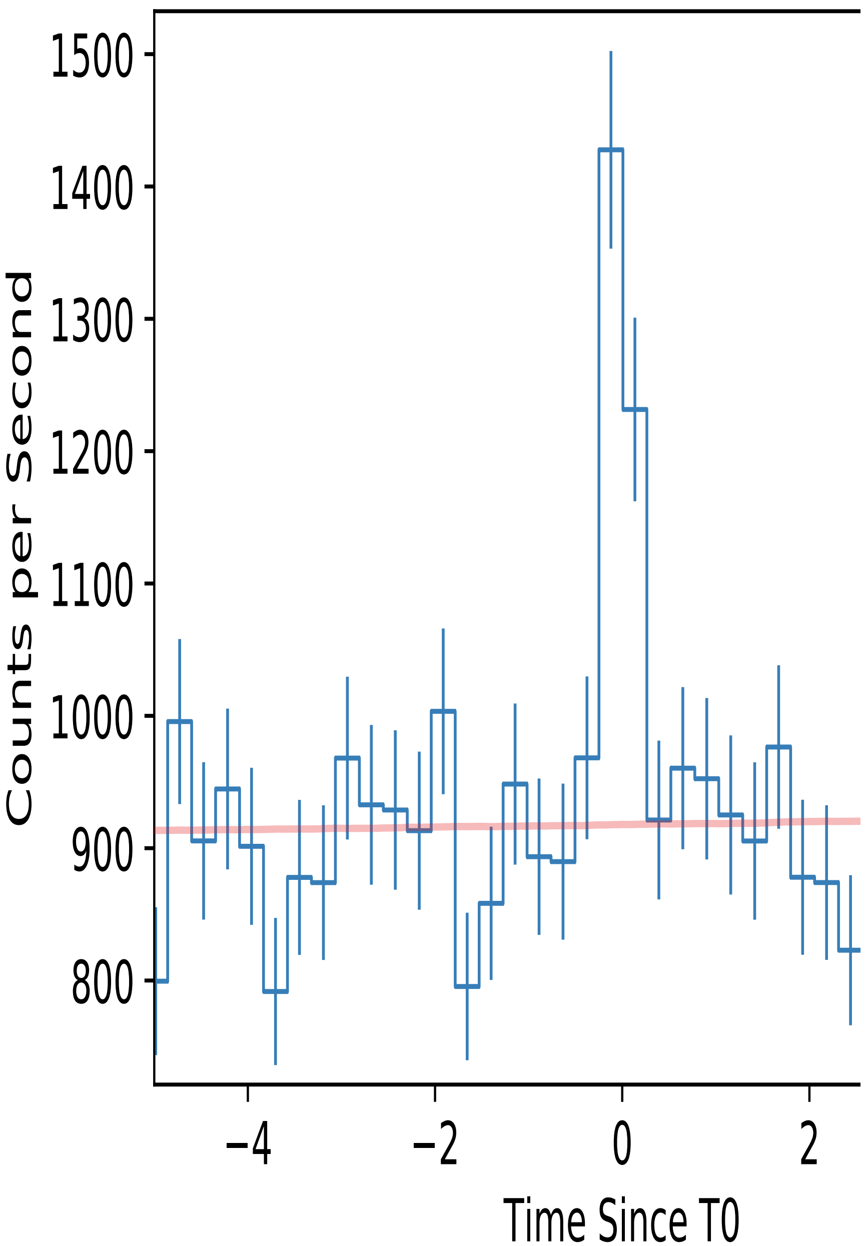
Overview: Multi-messenger astronomy of compact binary mergers

Kenta Hotokezaka (Princeton)

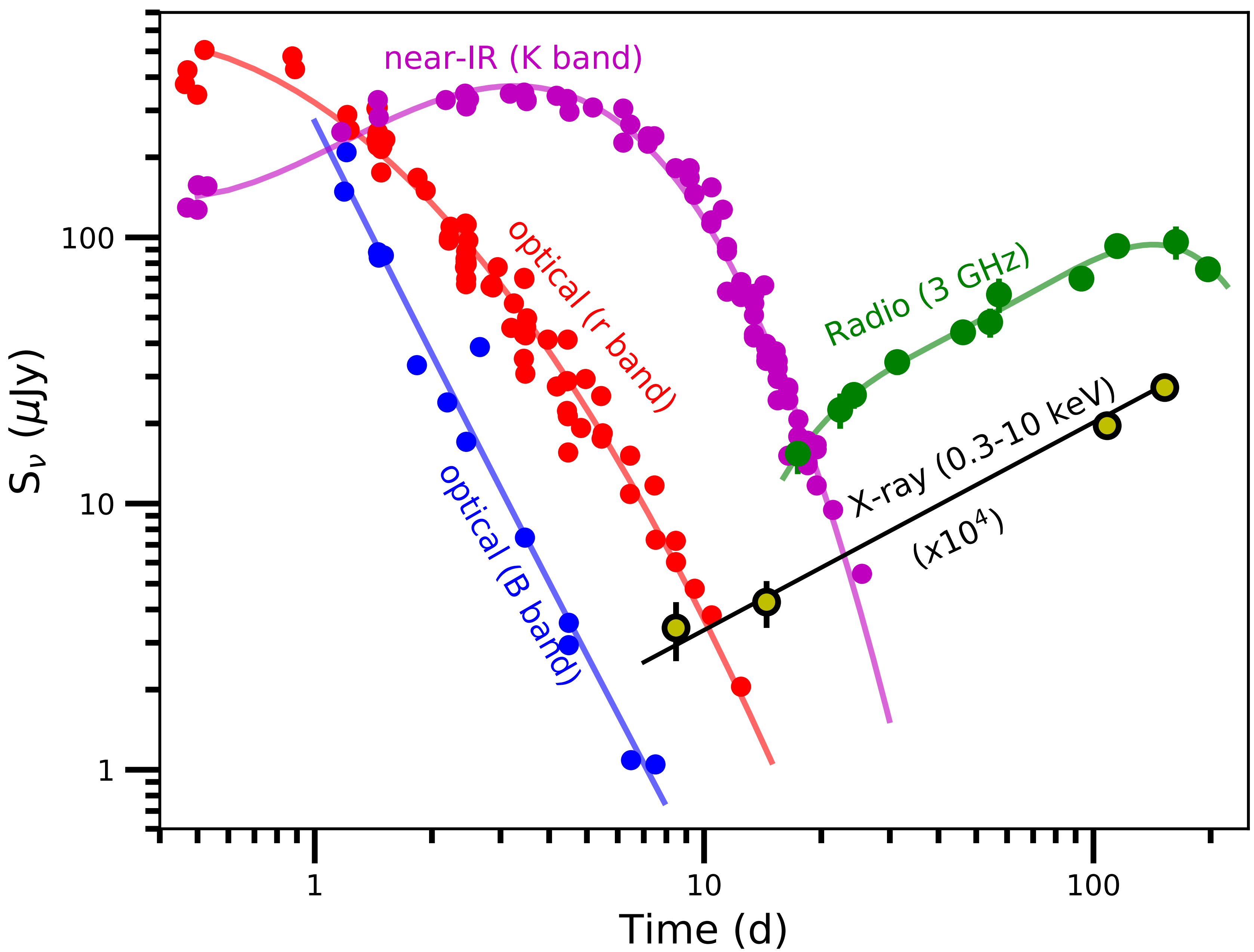
EM signal in GW170817

γ-ray pulse



Kilonova
(radioactivity)

Afterglow
(Jet's Kinetic energy)

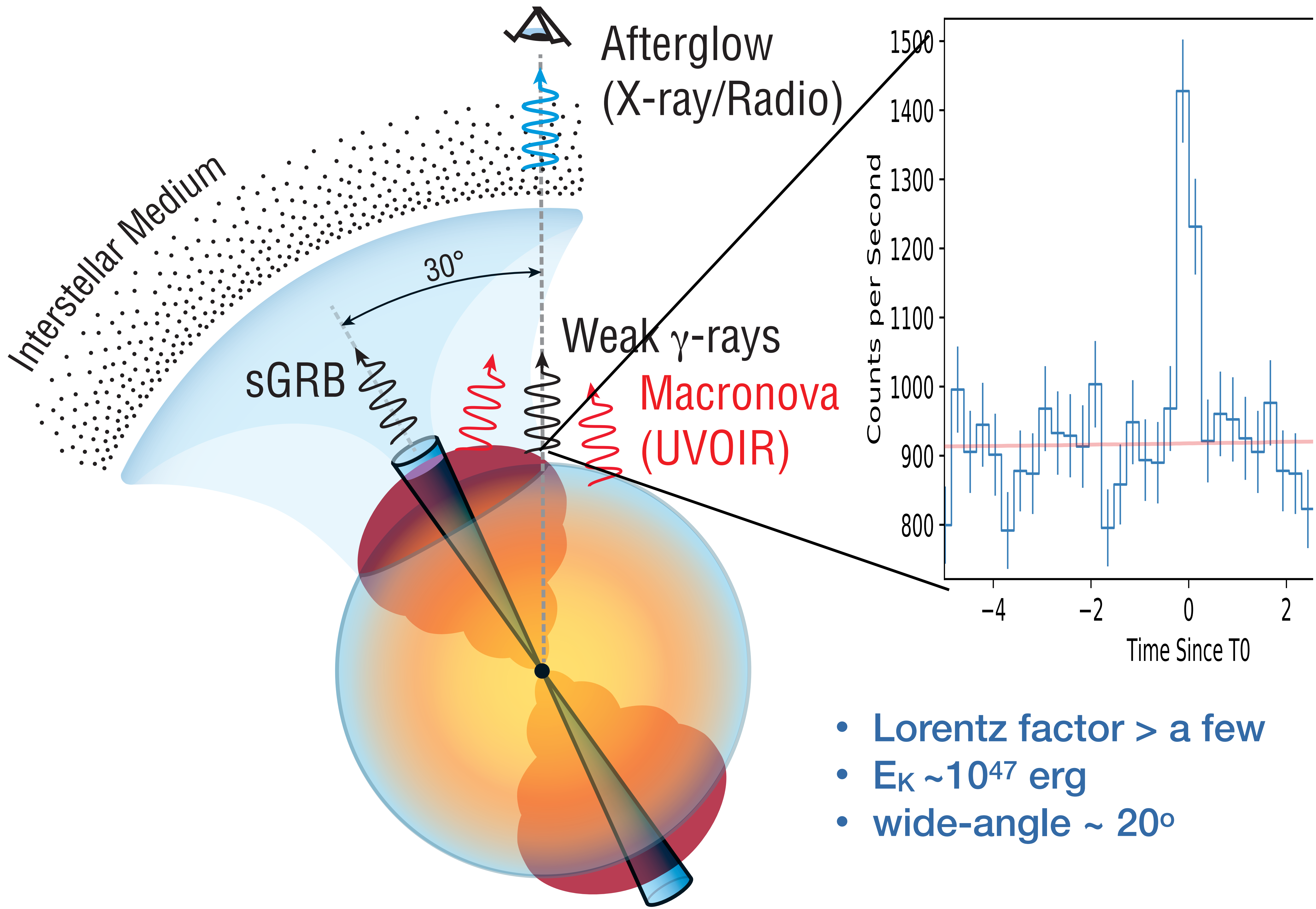


Energy in radiation:

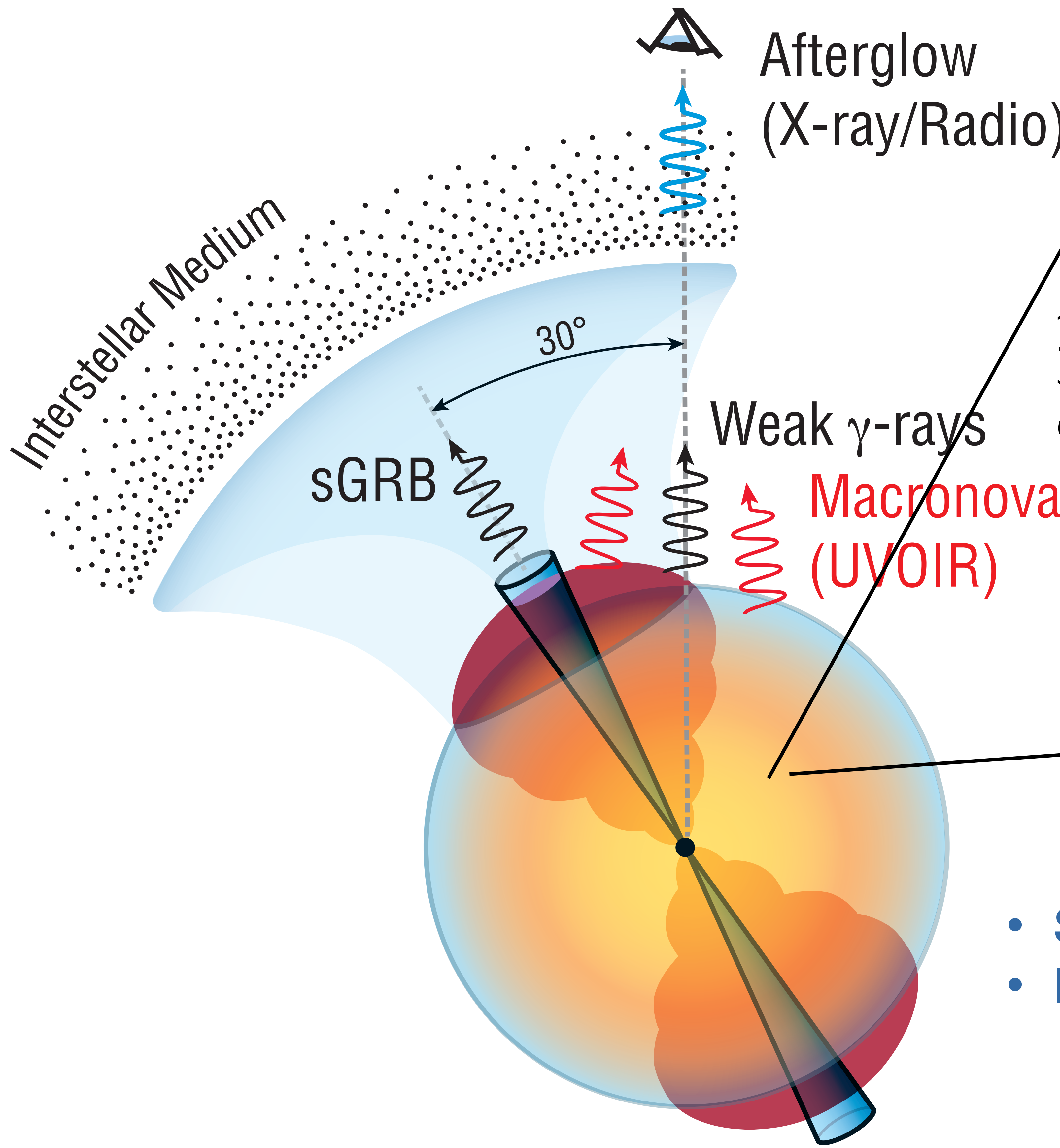
~10^{47} erg

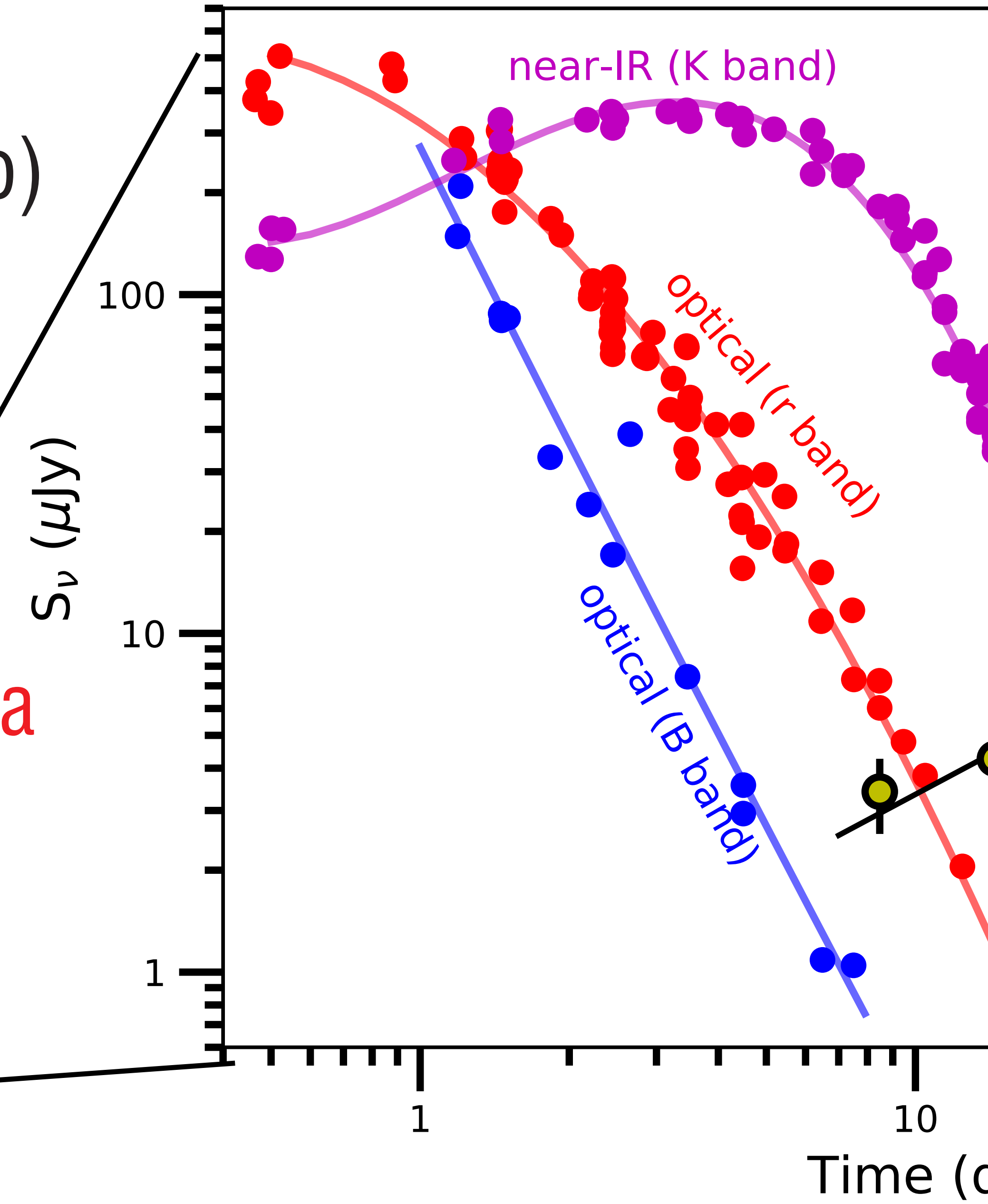
~10^{47} erg

~10^{47} erg

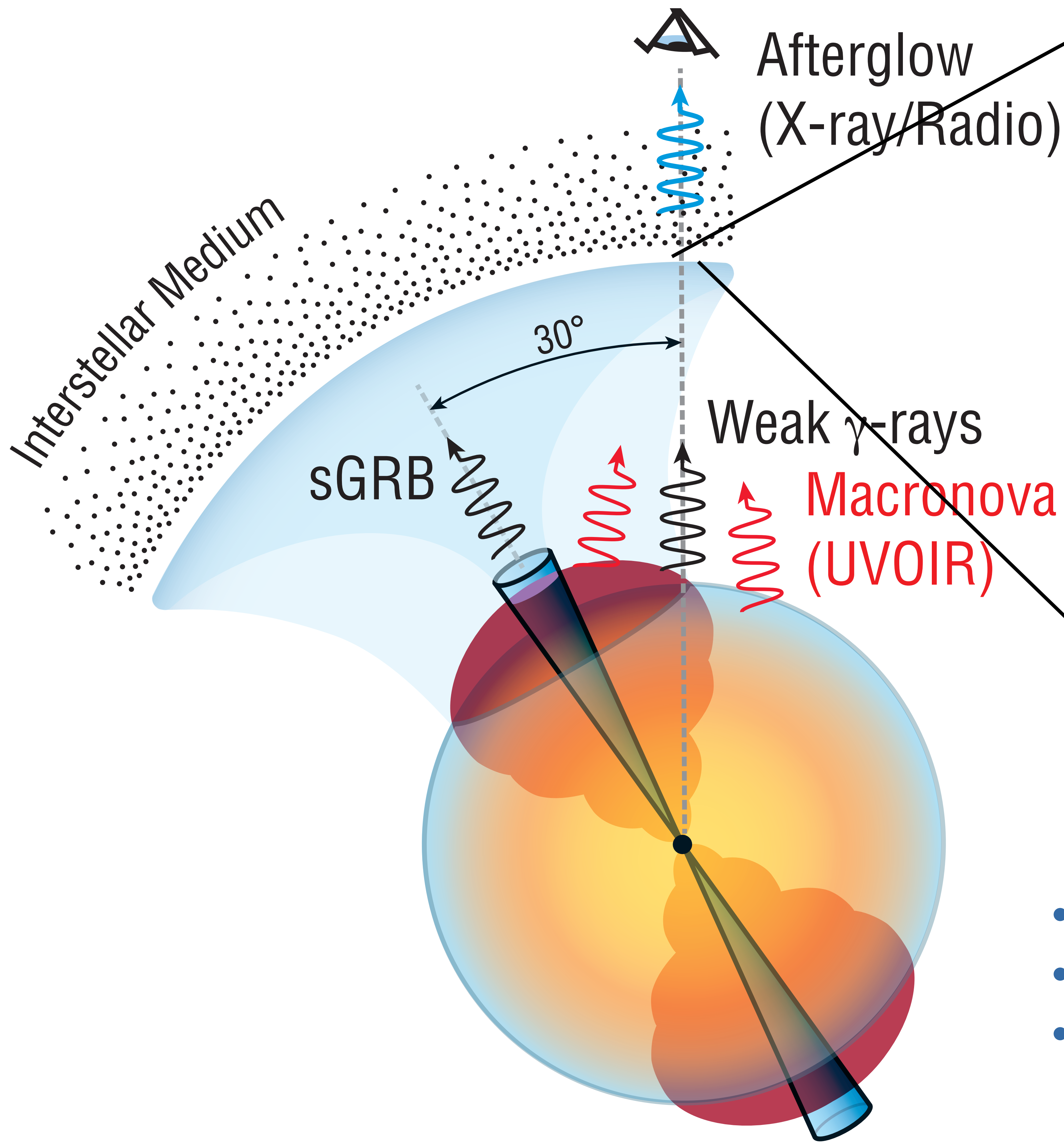


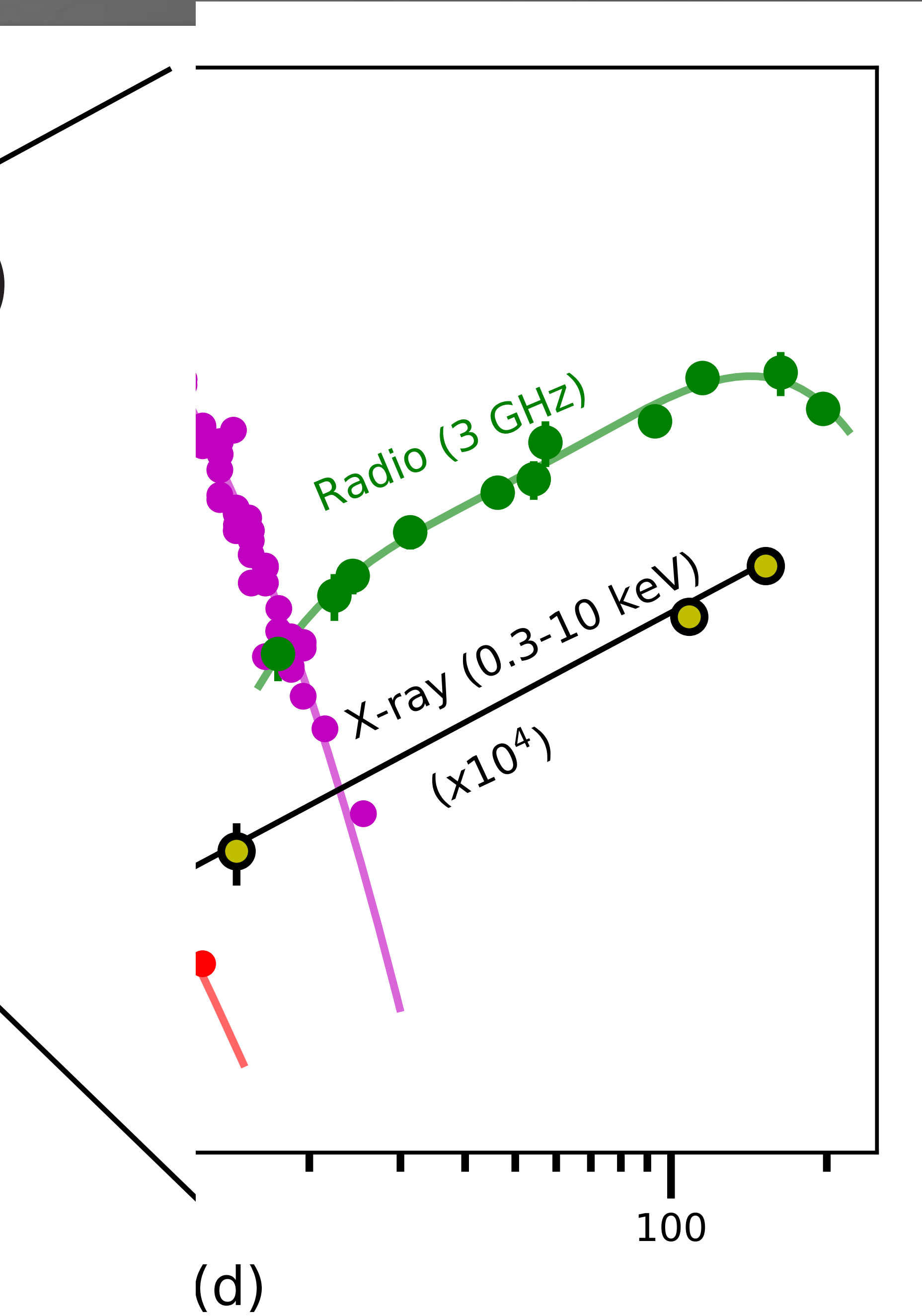
- Lorentz factor > a few
- $E_K \sim 10^{47}$ erg
- wide-angle ~ 20°





- Subrelativistic ~ 0.1c
- M ~ $0.05M_{sun}$ E_K ~ 10^{51} erg





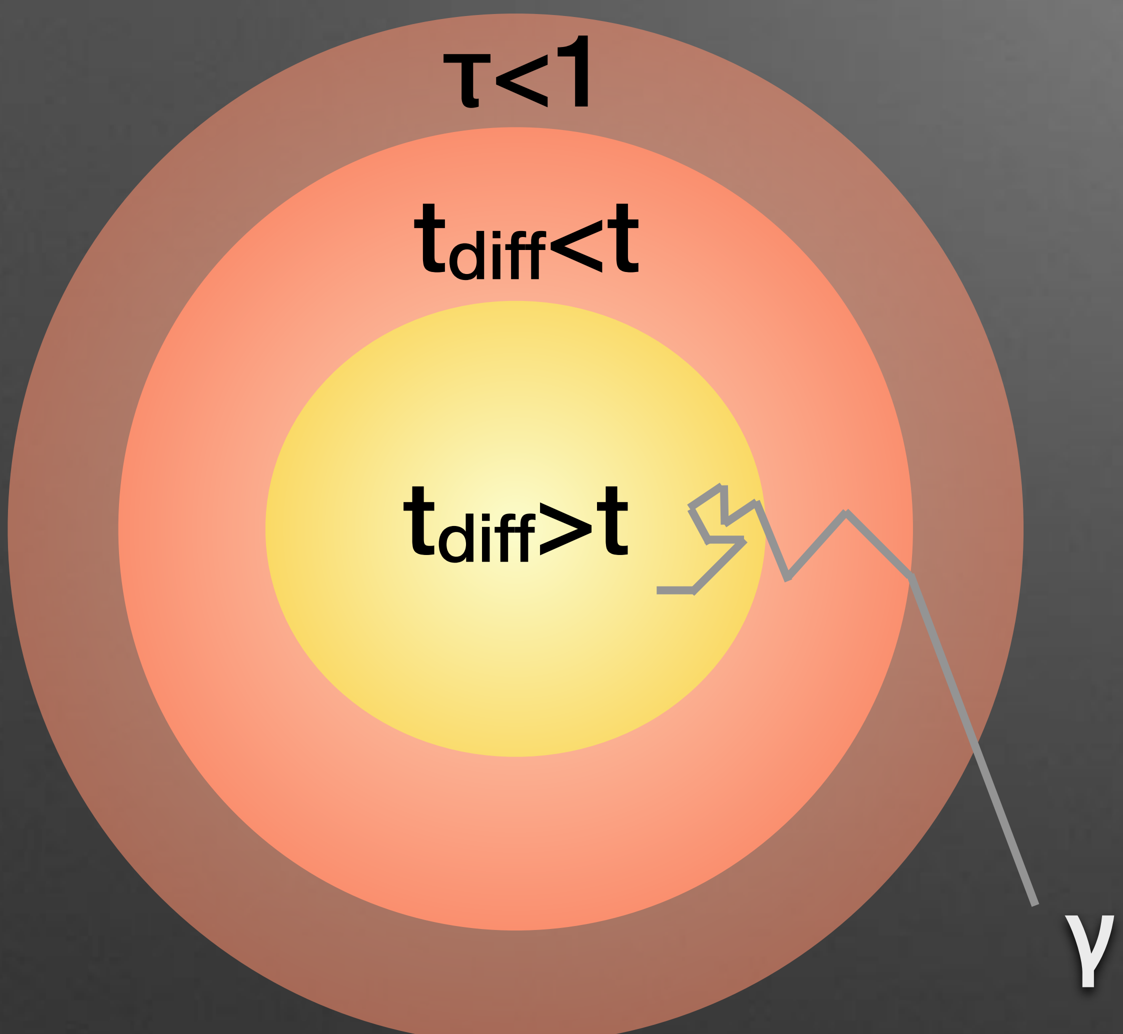
- Lorentz factor > a few
- $E_K \sim 10^{47}$ erg
- wide-angle ~ 20^o

Outline

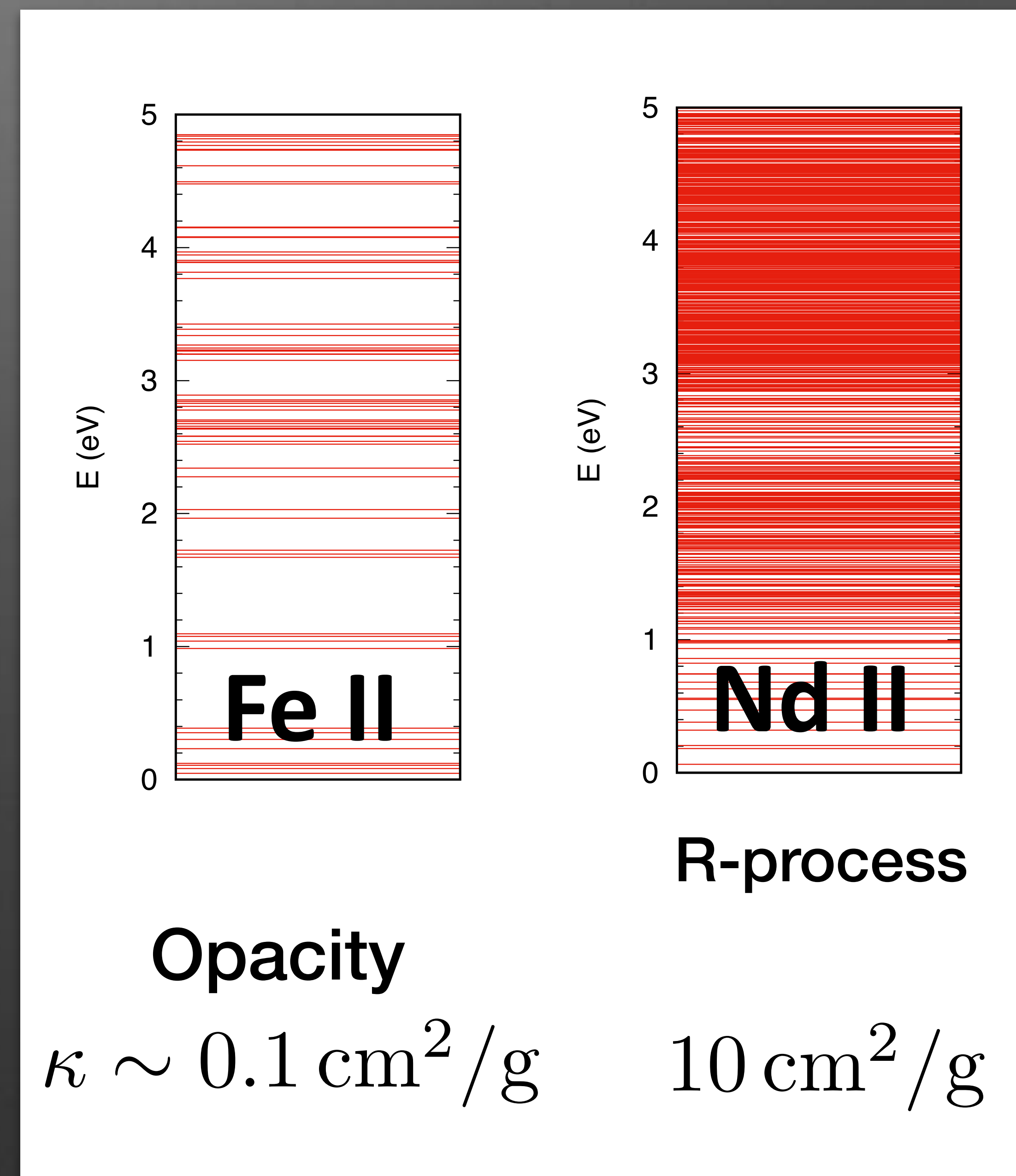
- Kilonova (GW170817 and future)
- Afterglow (detais by Poonam)
- Gamma-ray burst (details by Varun)
- High-energy Neutrino

Radioactive heat => Photon Luminosity

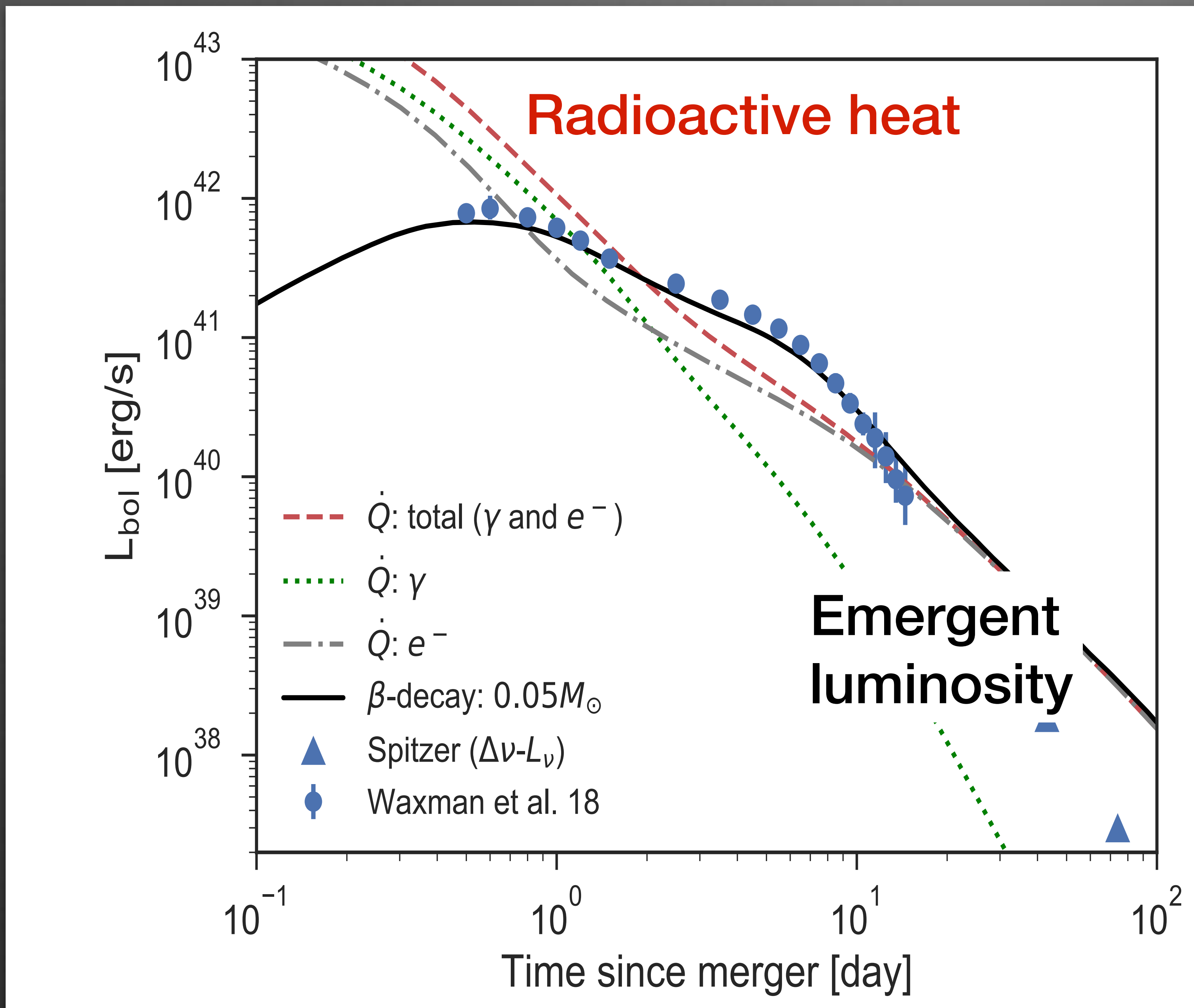
Expanding Ejecta: $0.01 M_{sun}$, $0.1c$



Photons are blocked by atomic transitions



Kilonova in GW170817



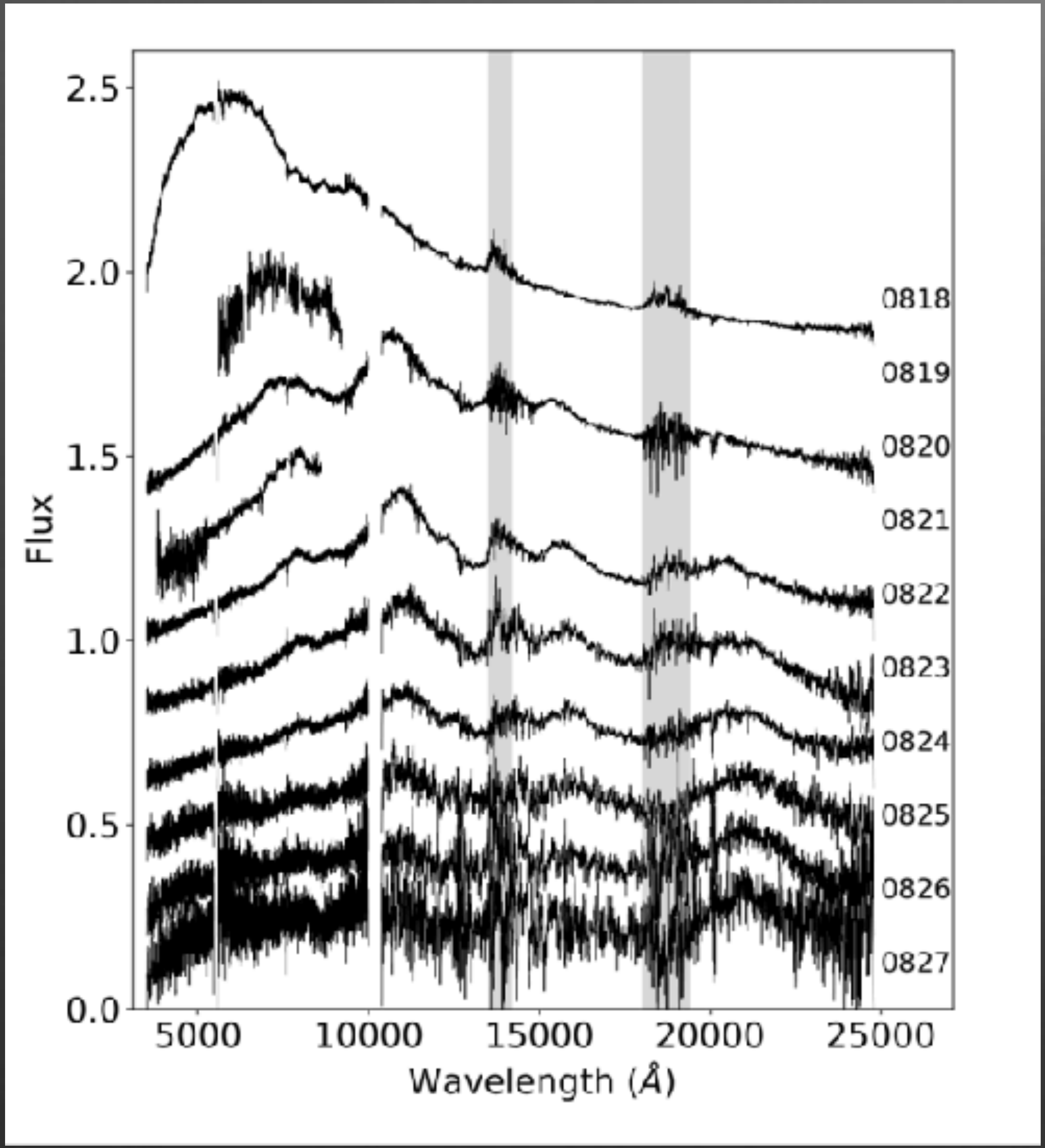
1) The light curve follows the radioactive heating rate.
=> r-process production

2) The peak time is < 0.5 day.
=> low opacity.

3) The light curve approach the heating rate ~ 10 day
=> high opacity.

KH & Nakar in prep.

Spectral Evolution



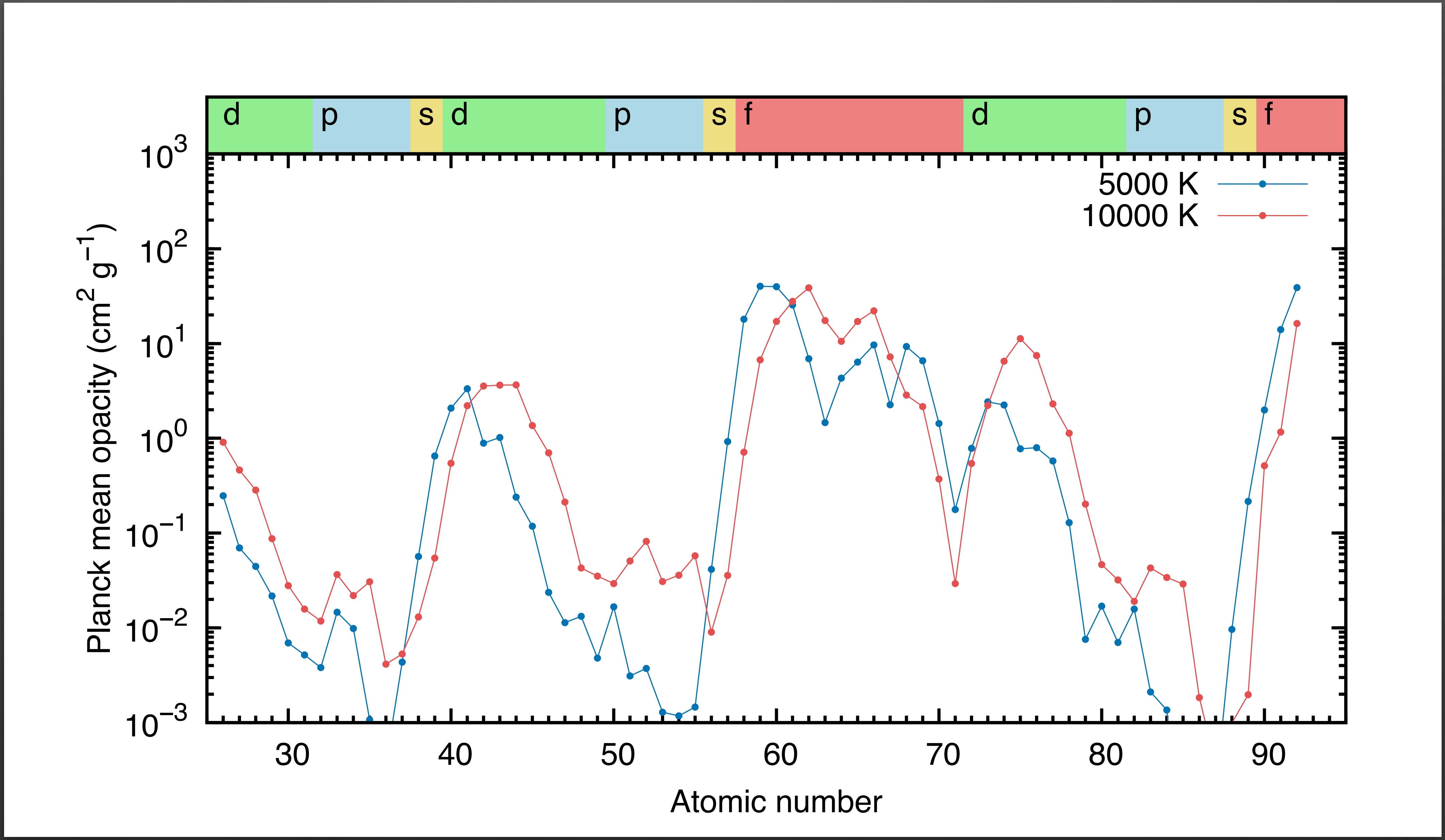
Black Body spectrum ~ 1 day.

Some broad features later.

More emission in the near infrared.
=> suggests heavy elements.

Atomic Opacity

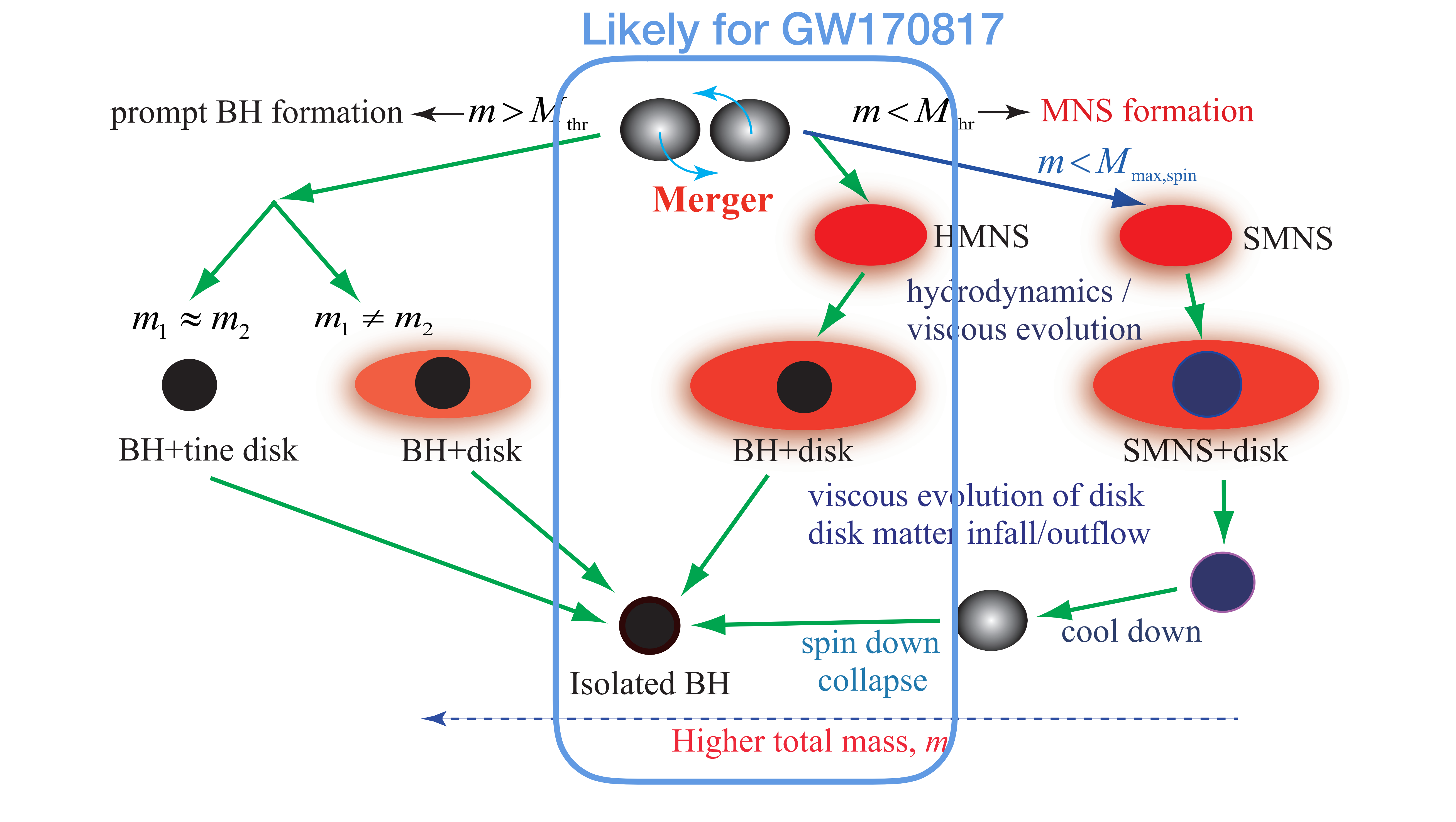
Tanaka+19



Low A: Low opacity

High A: High opacity

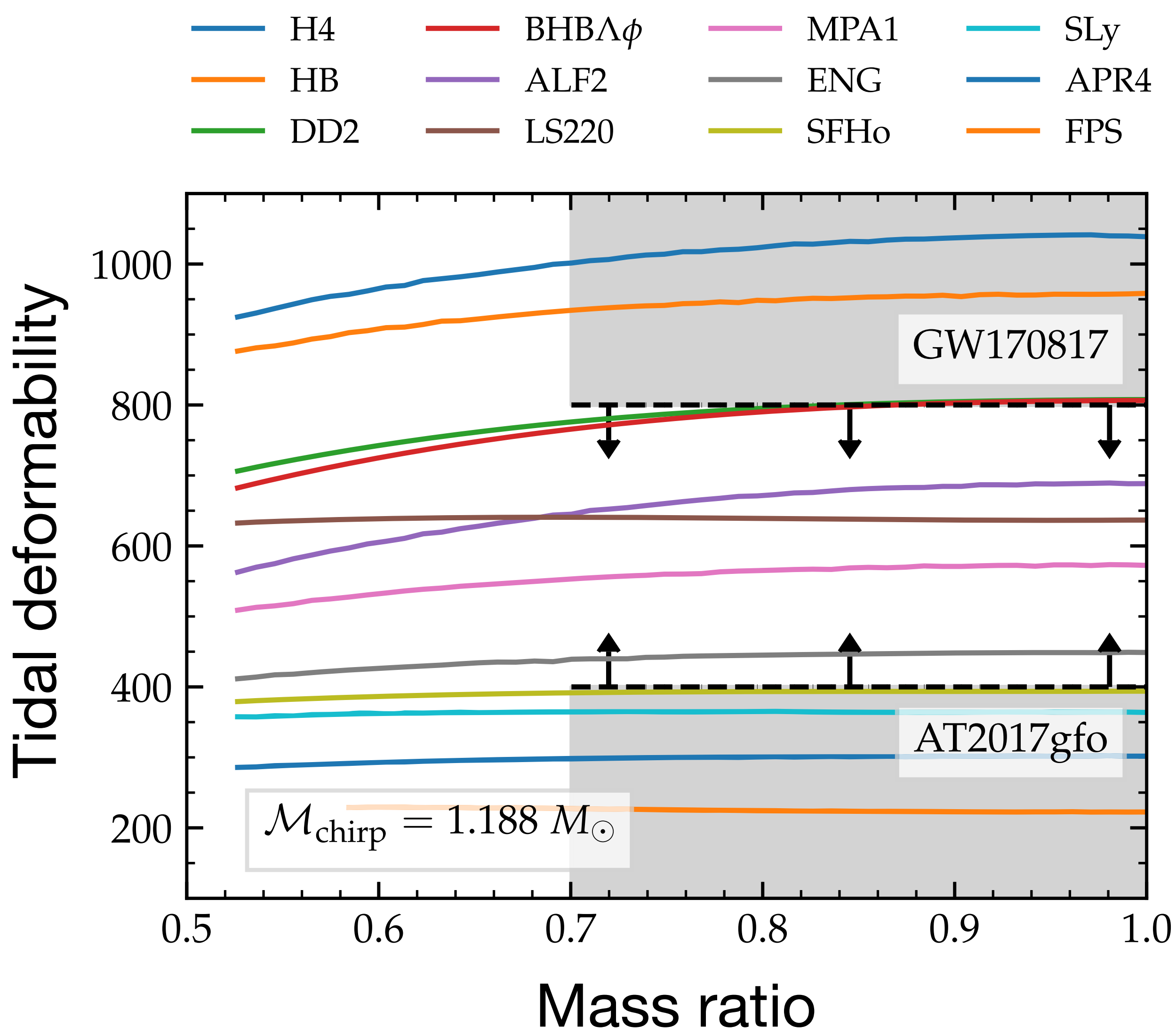
Different channels



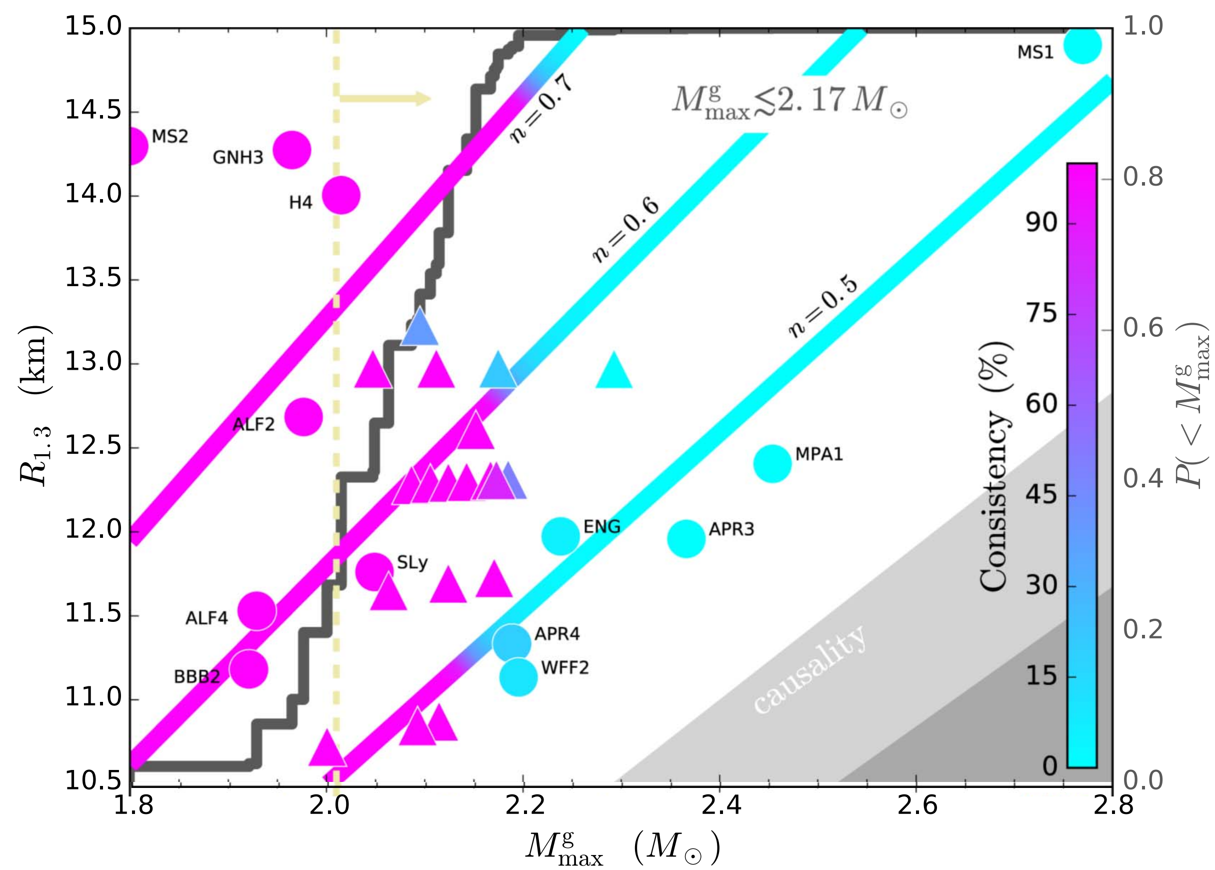
We may see variation in the kilonova emission of future merger events.

GW + Kilonova => NS EOS

The kilonova signal suggests hypermassive neutron star formation leading to constraints on NS EoS.



Radice et al 2018



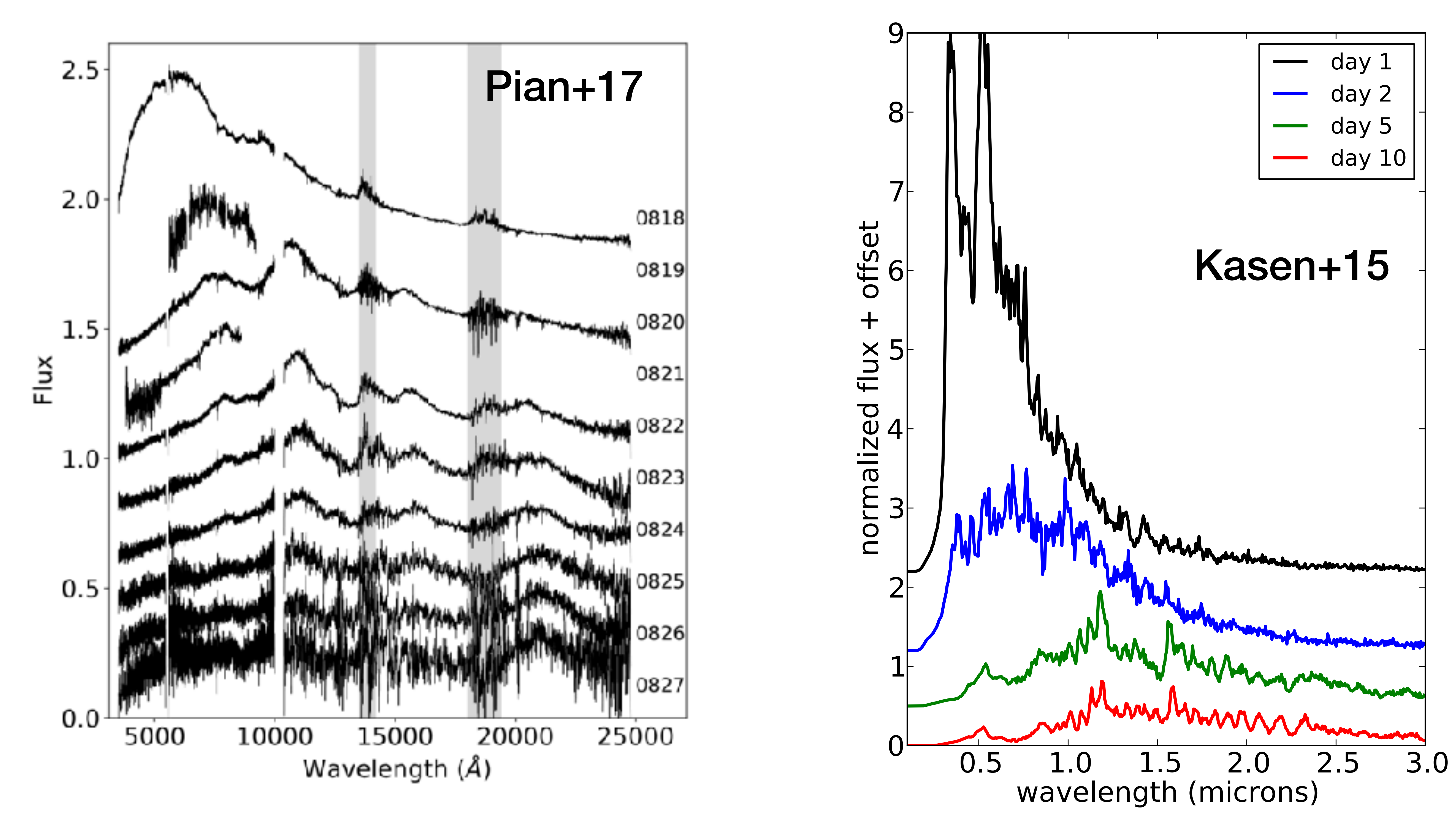
Margalit and Metzger 2017

$$400 \lesssim \tilde{\Lambda} \lesssim 800$$

$$M_{\rm max} \lesssim 2.17 M_\odot$$

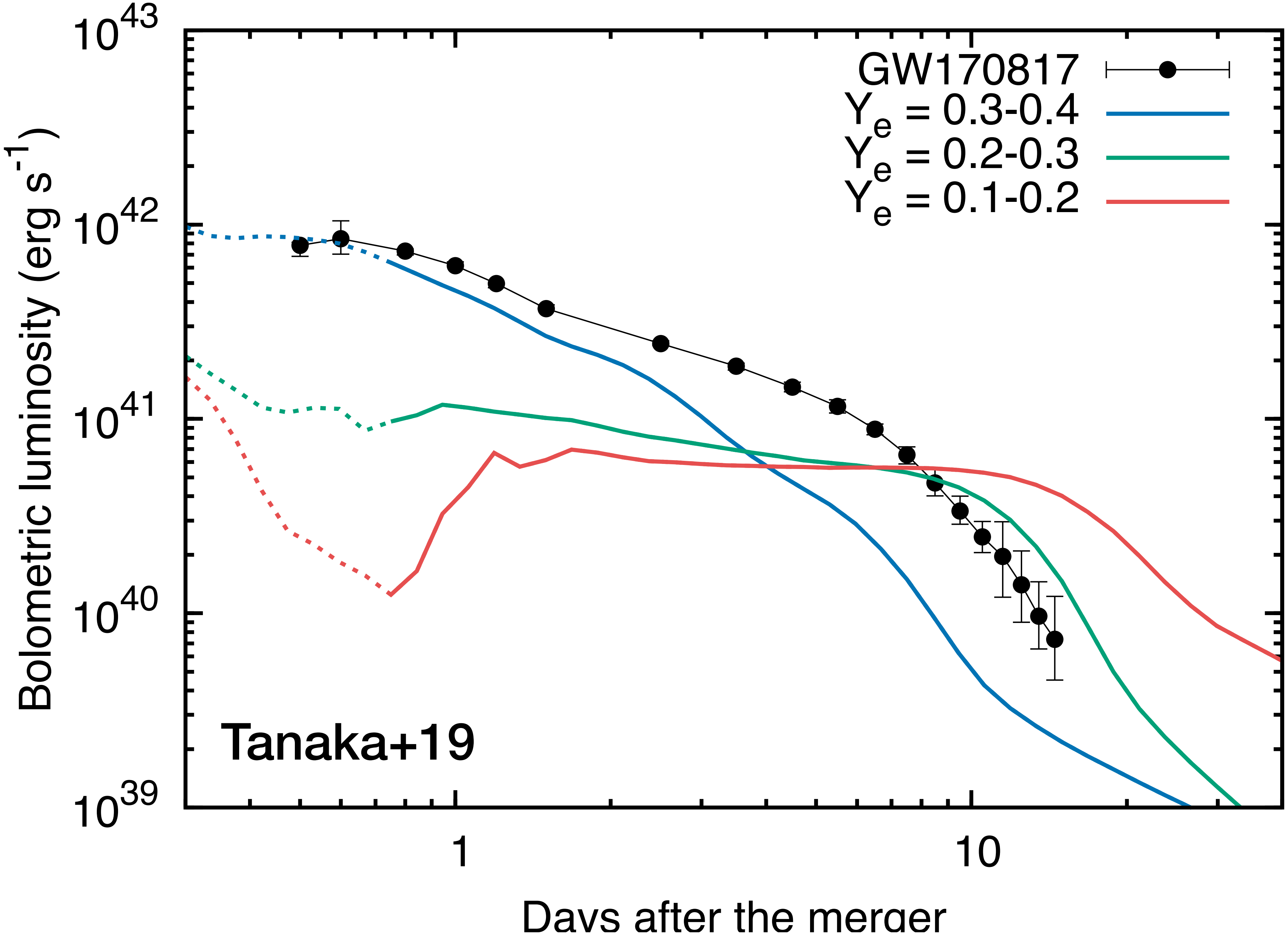
See also Baustein et al. 2017, Shibata et al. 2017, Ruiz et al. 2018.

Question: Why black body?



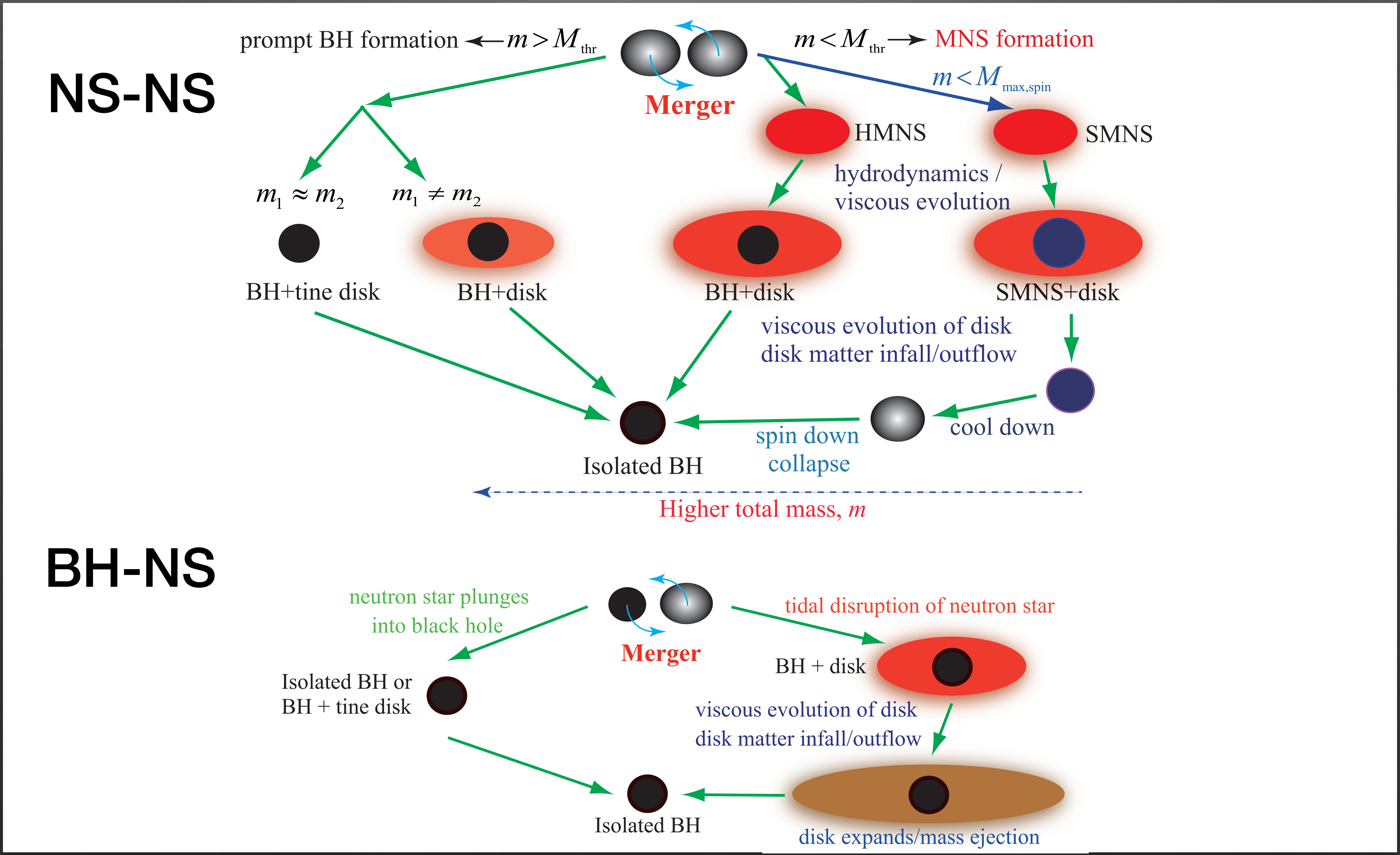
Strong atomic absorption is expected to modifies the BB spectrum even at very early times.

Question: Why light curve is so smooth?



Two component models (low & high opacities) generally predict a bump in the light curve but we didn't see it in GW170817.

Question: Different channels make difference?



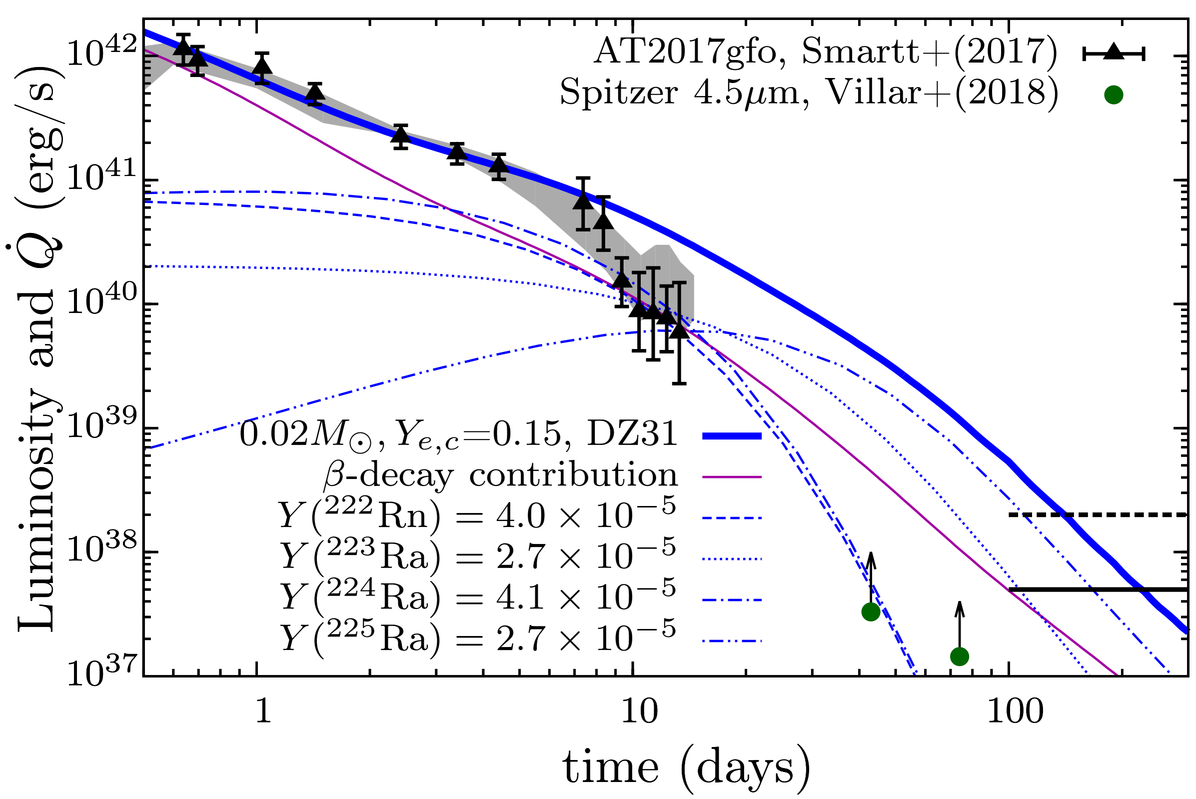
It will be very helpful for astronomers to know masses.

Toward identifying heavy elements in kilonova signal

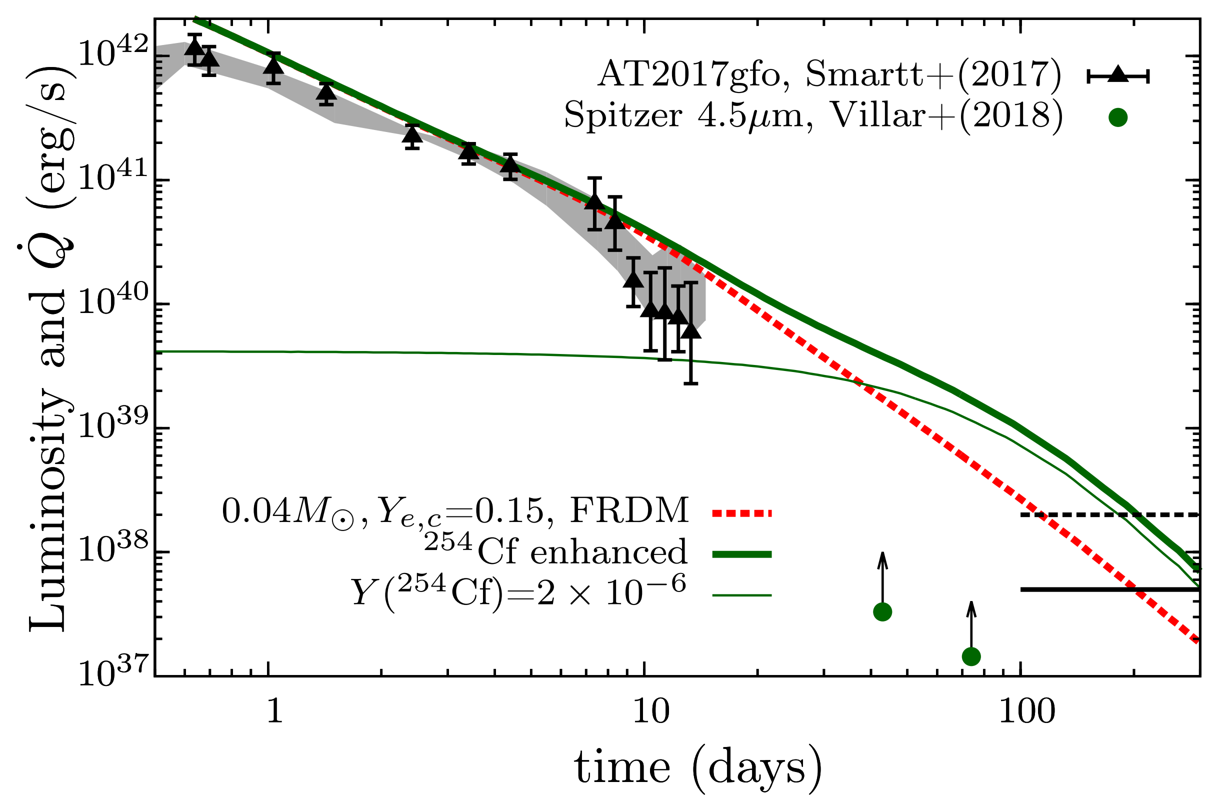
α-decay and fission

Wu+18, Zhu+18

α-decay (A=222-225)

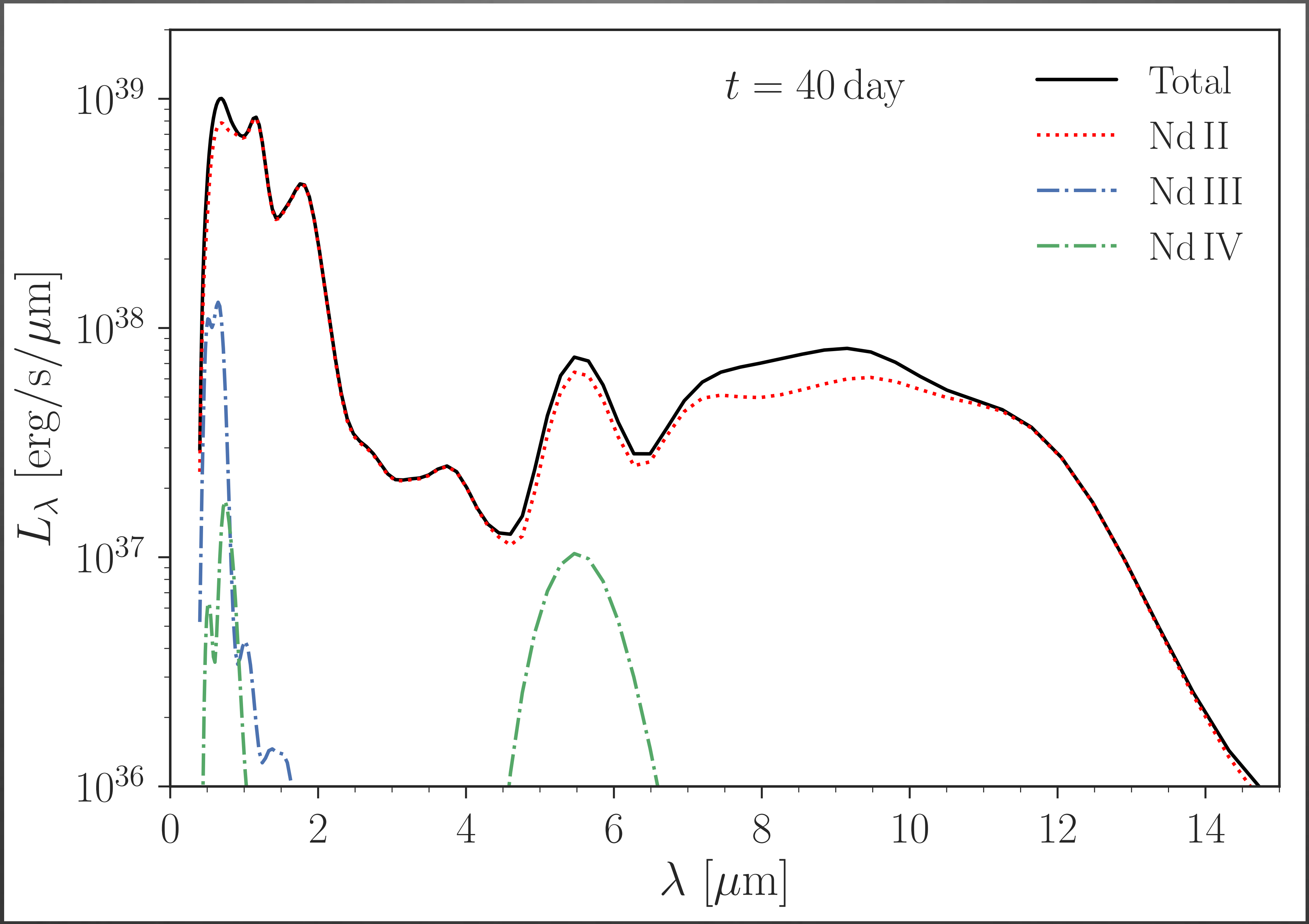


Fission (A>250)



Radioactivity of very heavy nuclei may be seen as an excess in the late light curve.

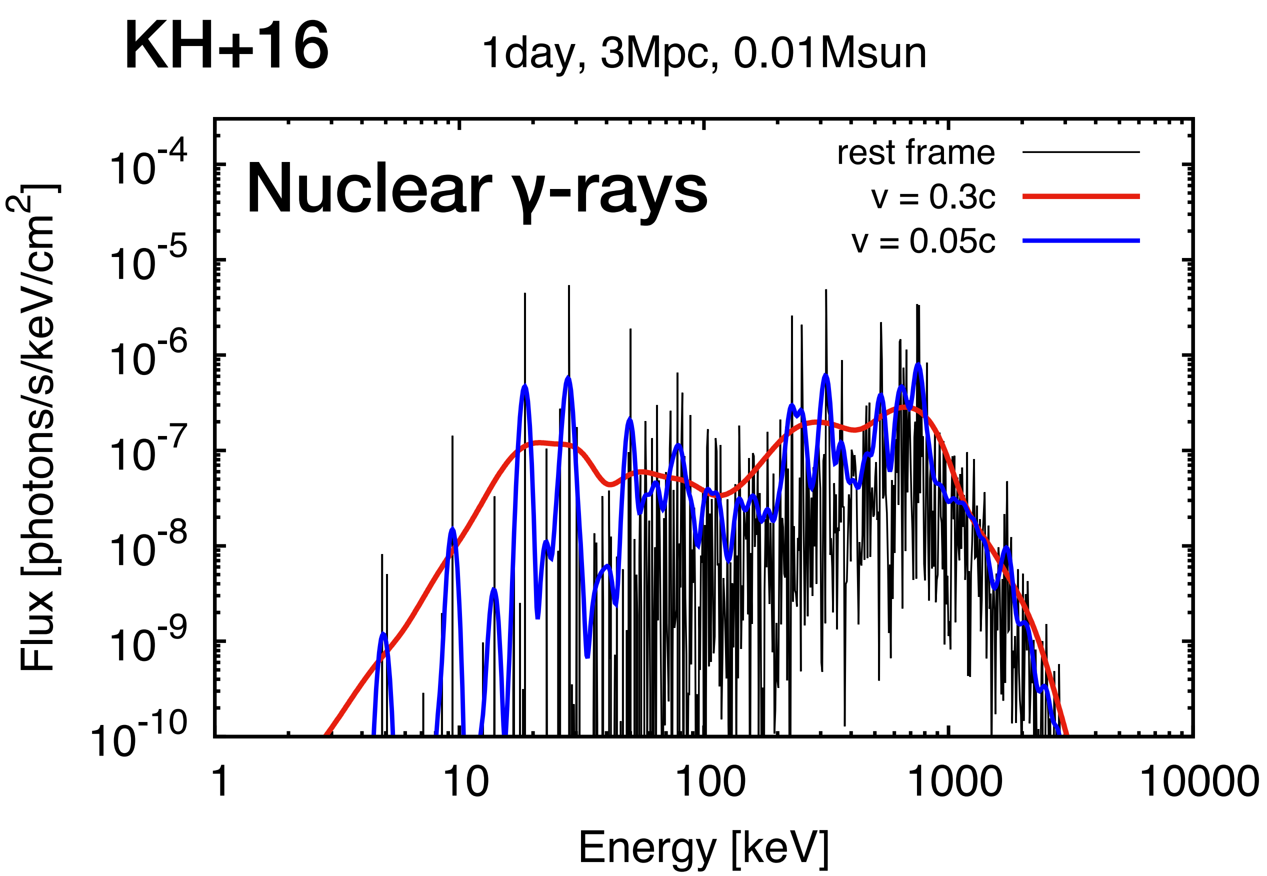
Nebular emission (neodymium kilonova)



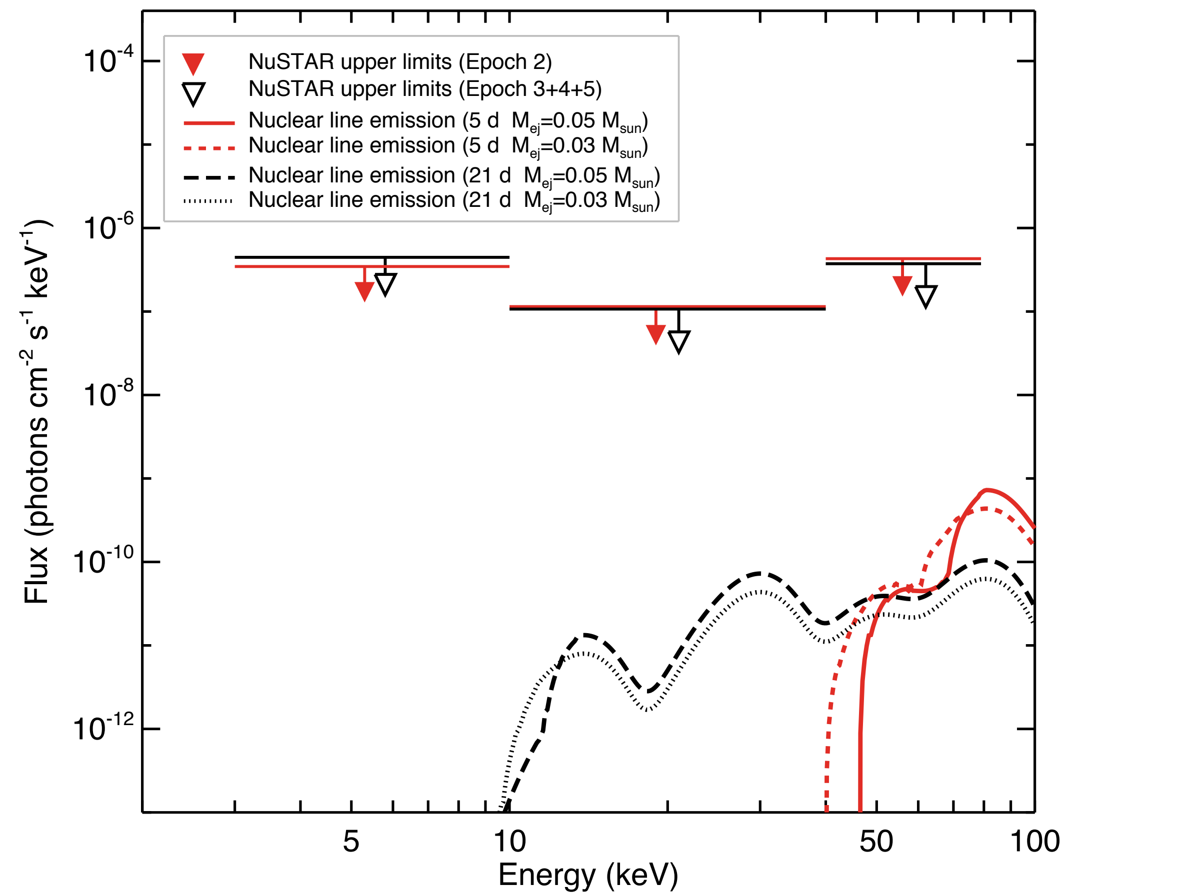
KH + in prep.

Late-time emission is composed of emission lines.
JWST will easily see the spectrum at 100 Mpc.

Nuclear γ-ray emission

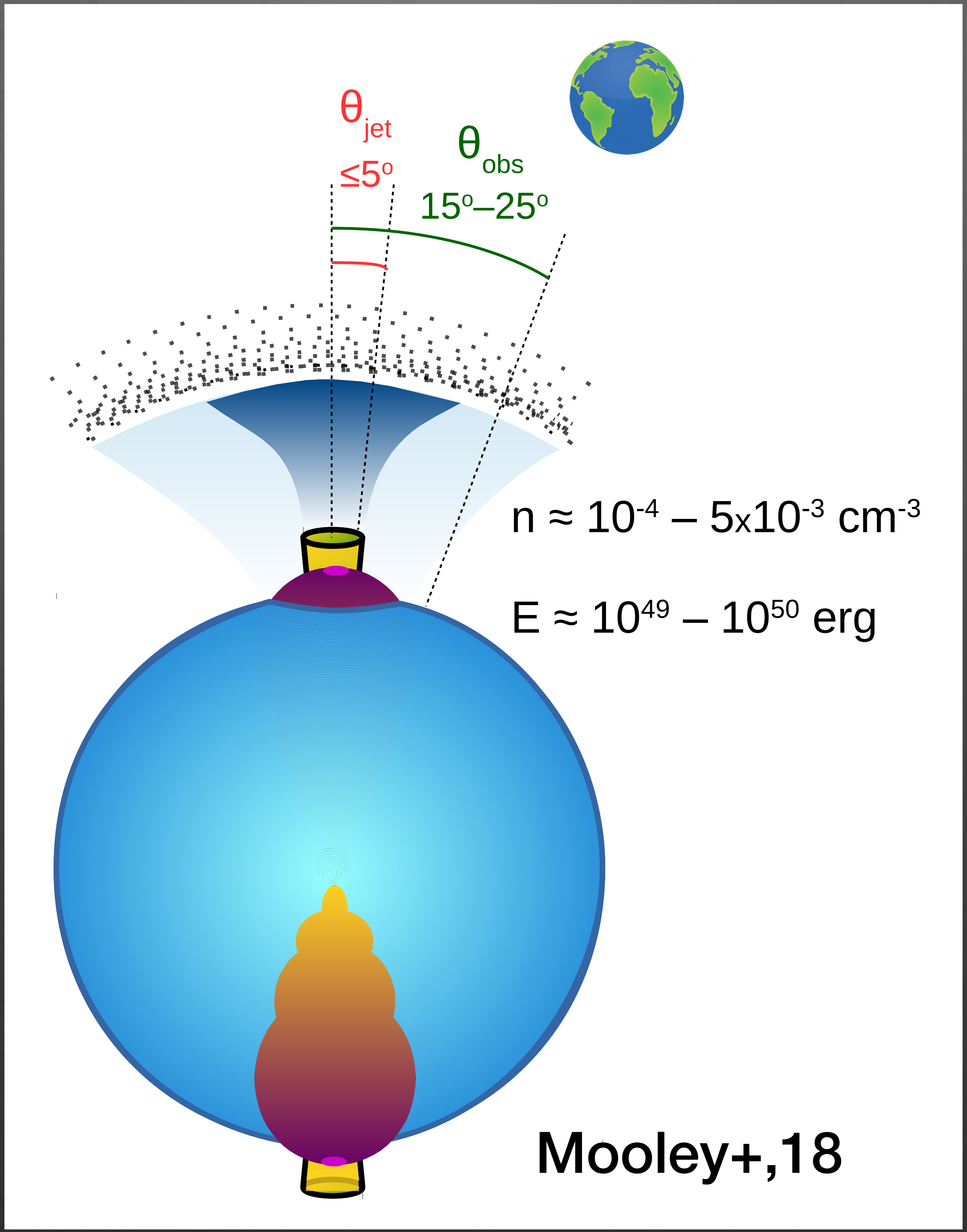


GW170817 (NuStar limit), Evans..KH+17

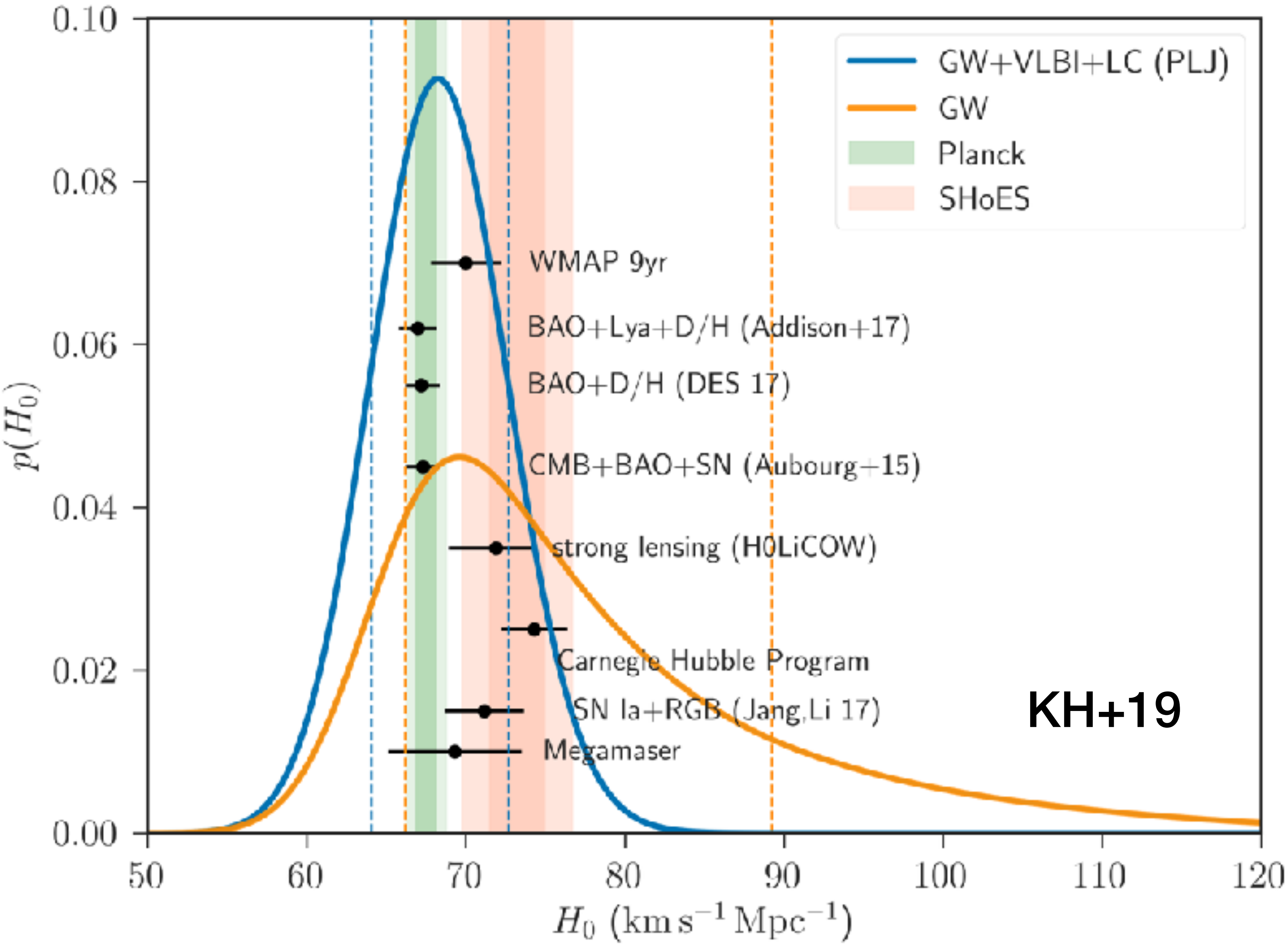


Detecting these lines would be an ultimate proof of the production of r-process nuclei in mergers but it is extremely difficult.

A jet in GW170817



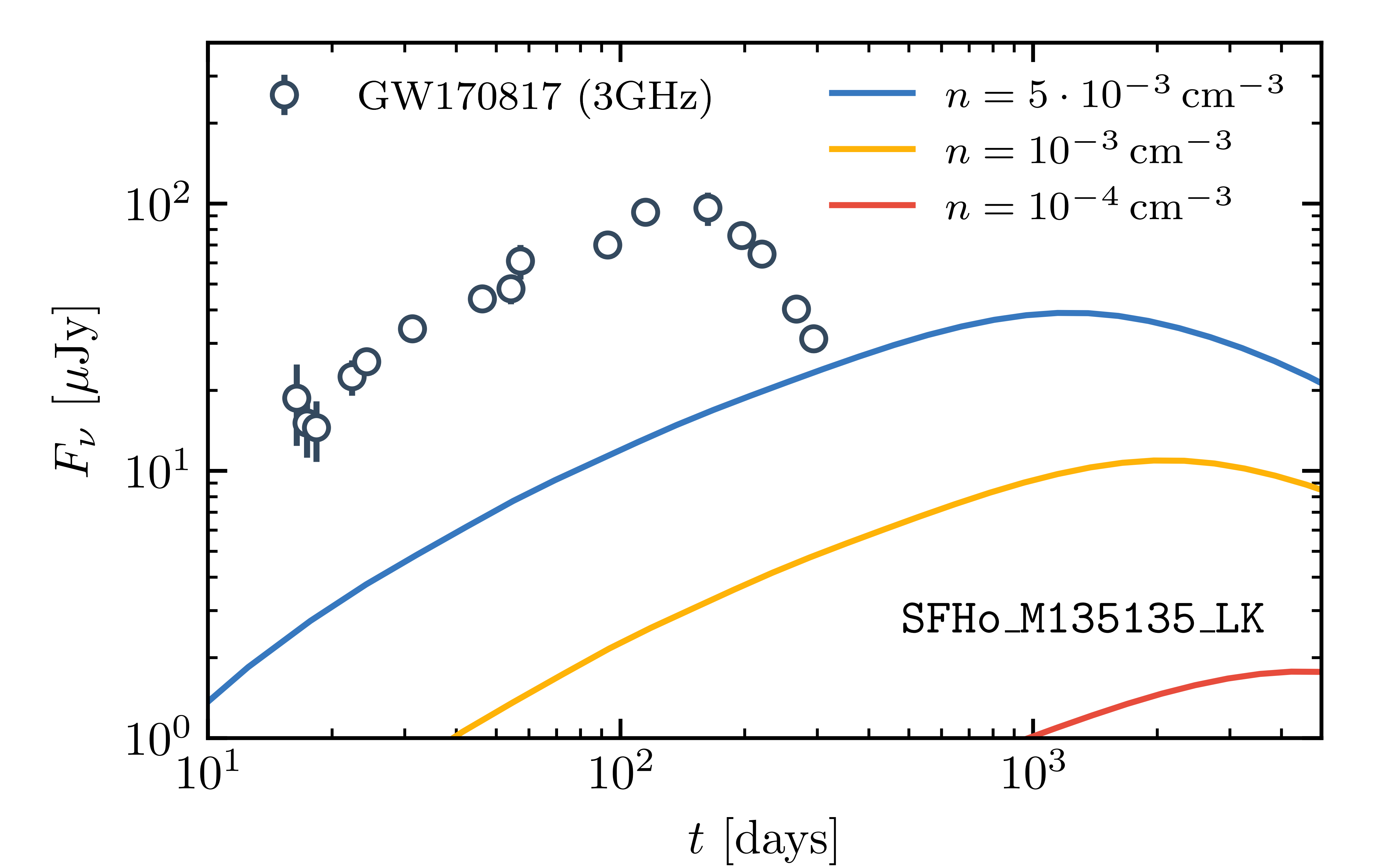
GW + light curve + VLBI => H0



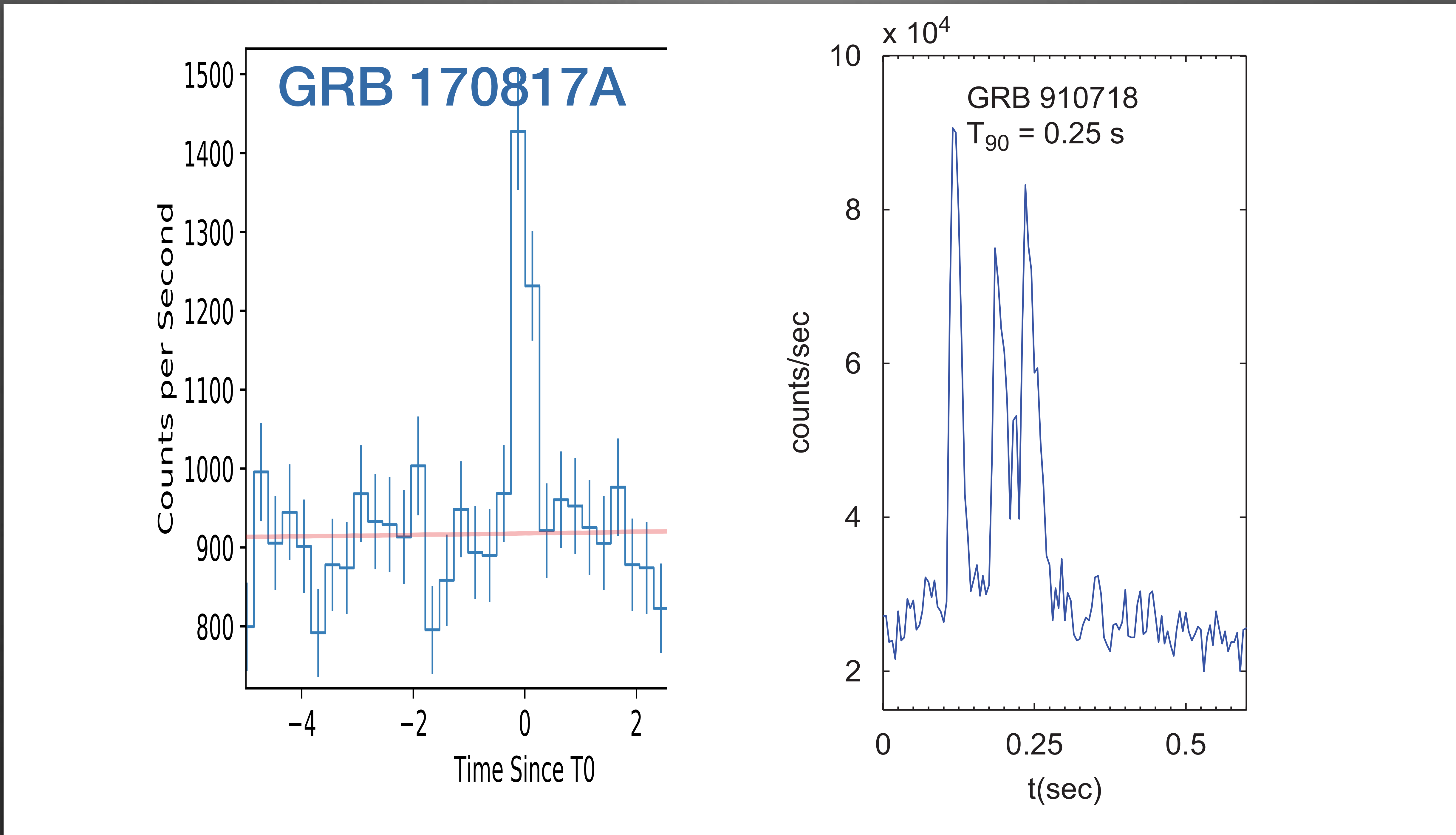
$68.1^{+4.5}_{-4.3}$ km/s/Mpc

The jet modeling is needed to be refined in future.

Near Future: afterglow of kilonova remnant

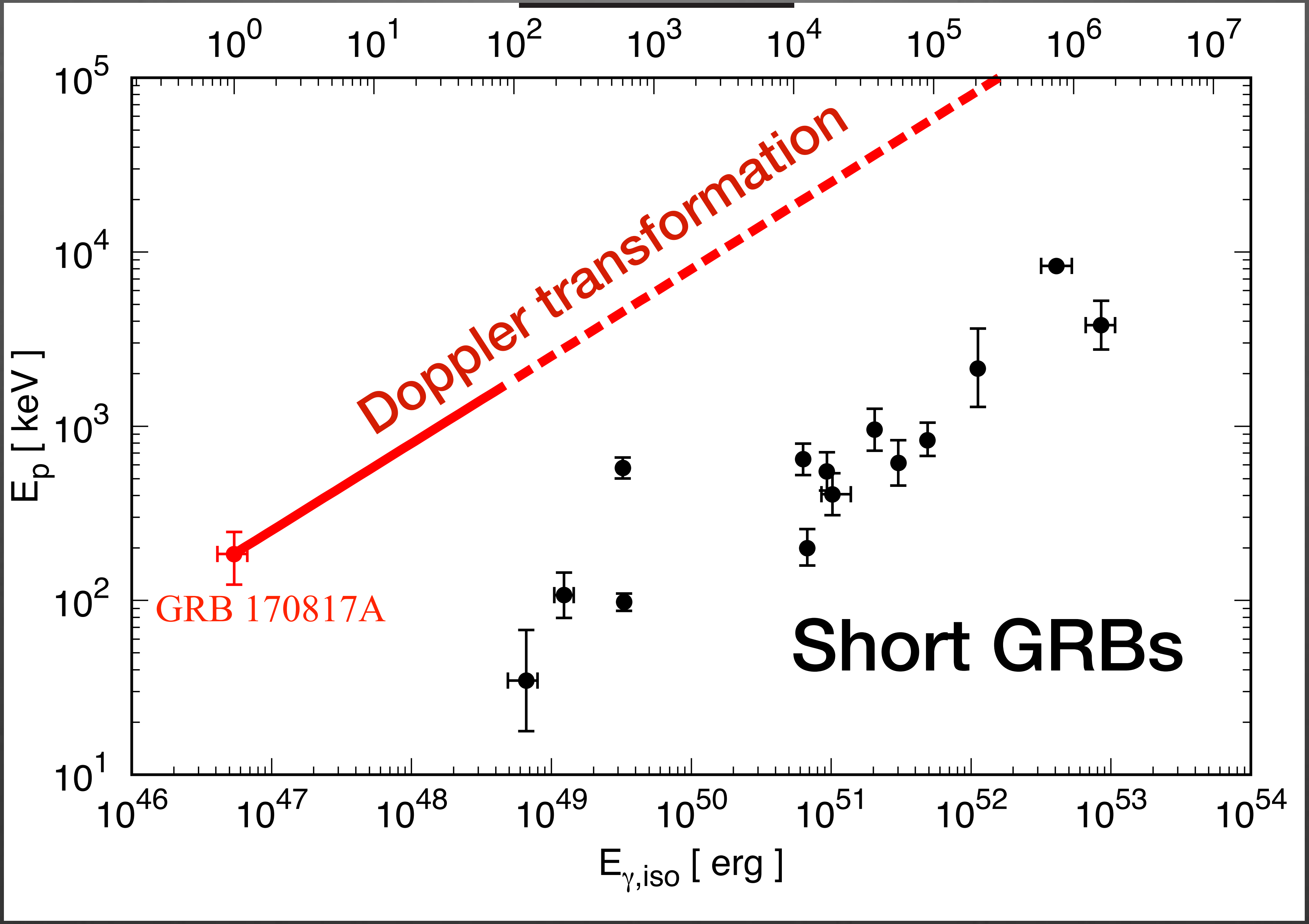


GRB 170817A



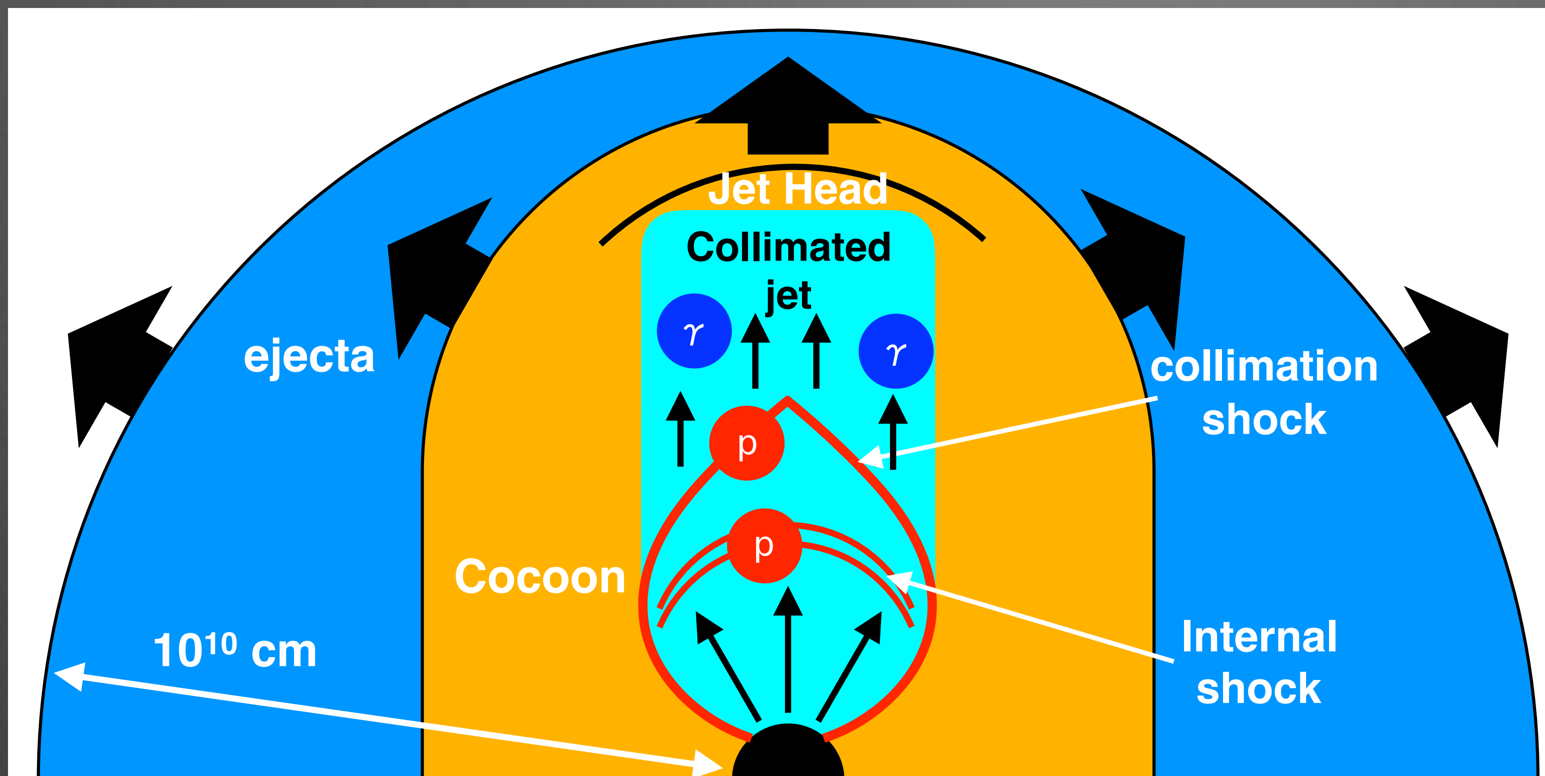
GRB 170817A
Counts per Second
1500
1400
1300
1200
1100
1000
900
800
−4
−2
0
2
Time Since T0
x 10^4
10
8
6
4
2
GRB 910718
T90 = 0.25 s
counts/sec
0
0.25
0.5
t(sec)

Difficulty of a simple off-axis model



Matsumoto, Nakar, Piran 18

High-energy Neutrinos



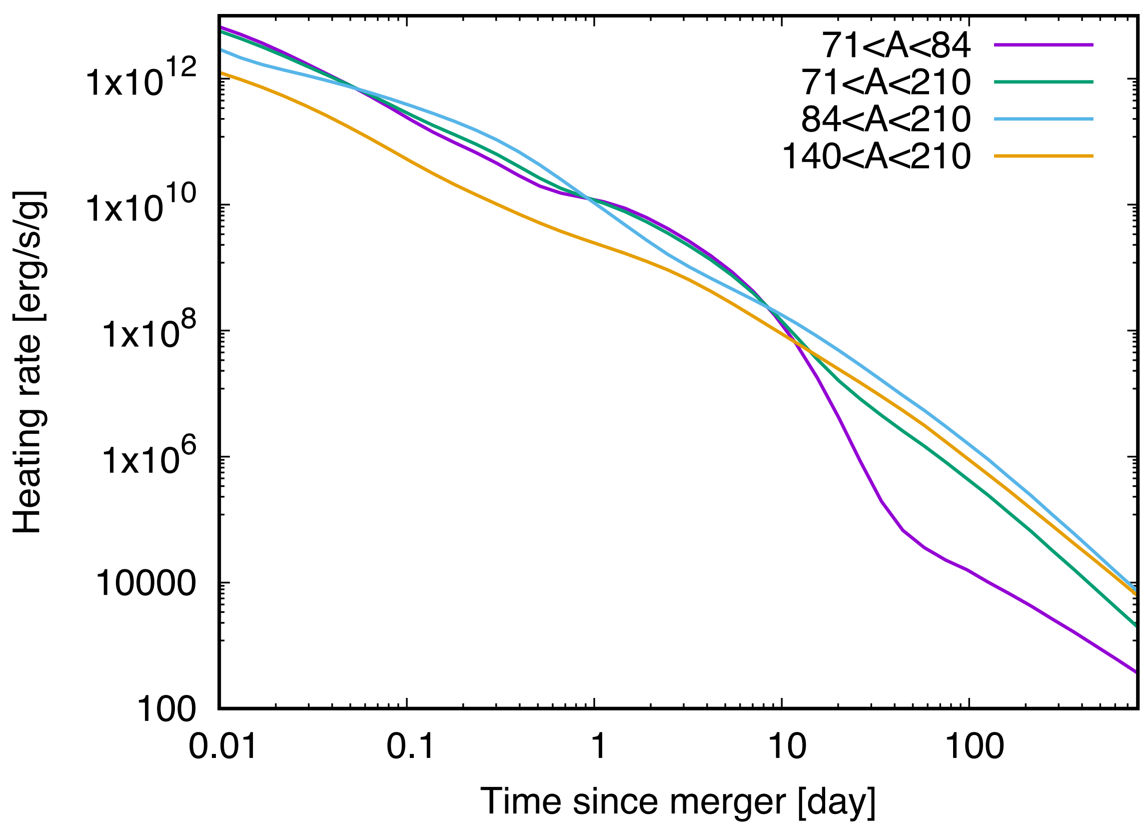
Kimura et al 18

Number of detected neutrinos from single event at 40 Mpc			
model	IceCube (up+hor)	IceCube (down)	Gen2 (up+hor)
A	2.0	0.16	8.7
B	0.11	7.0×10^{-3}	0.46

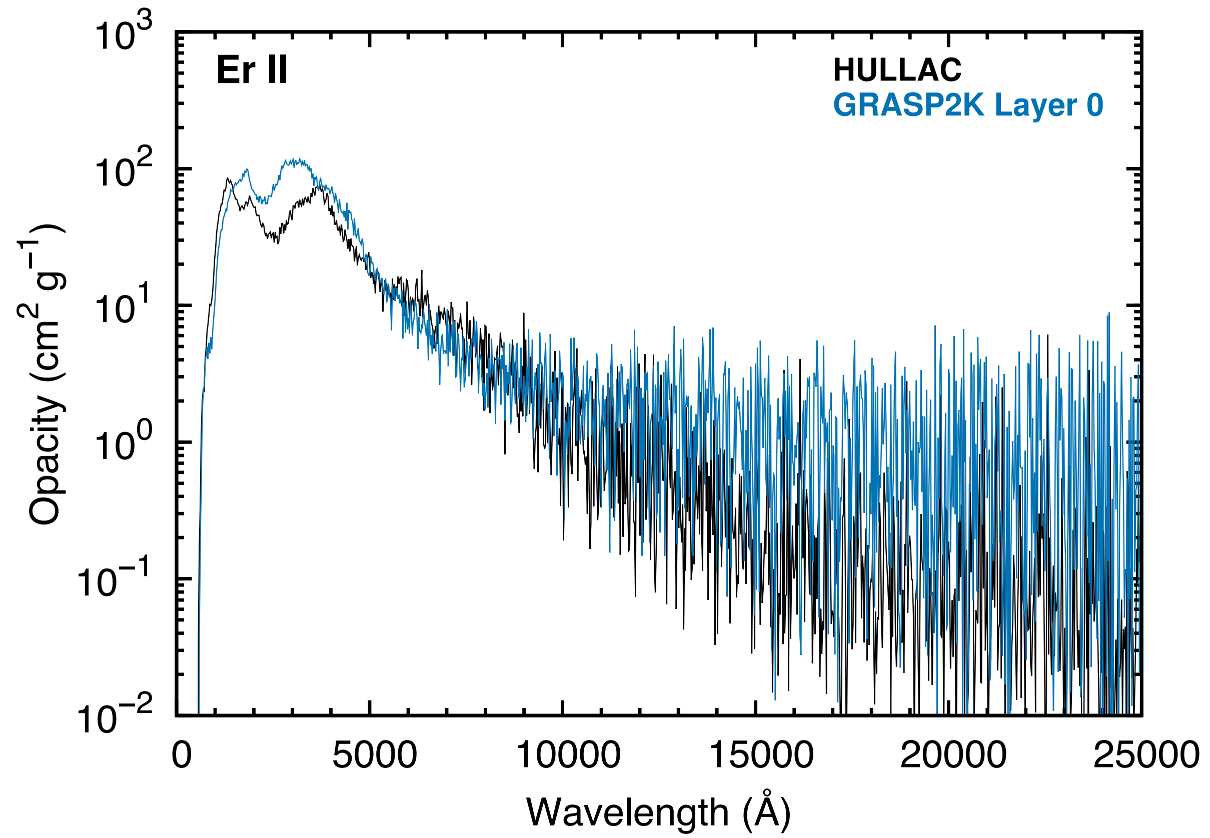
- γ-rays are hidden.
- Does particle acceleration really occur inside the ejecta?

Caveats

Heating rate different abundances.

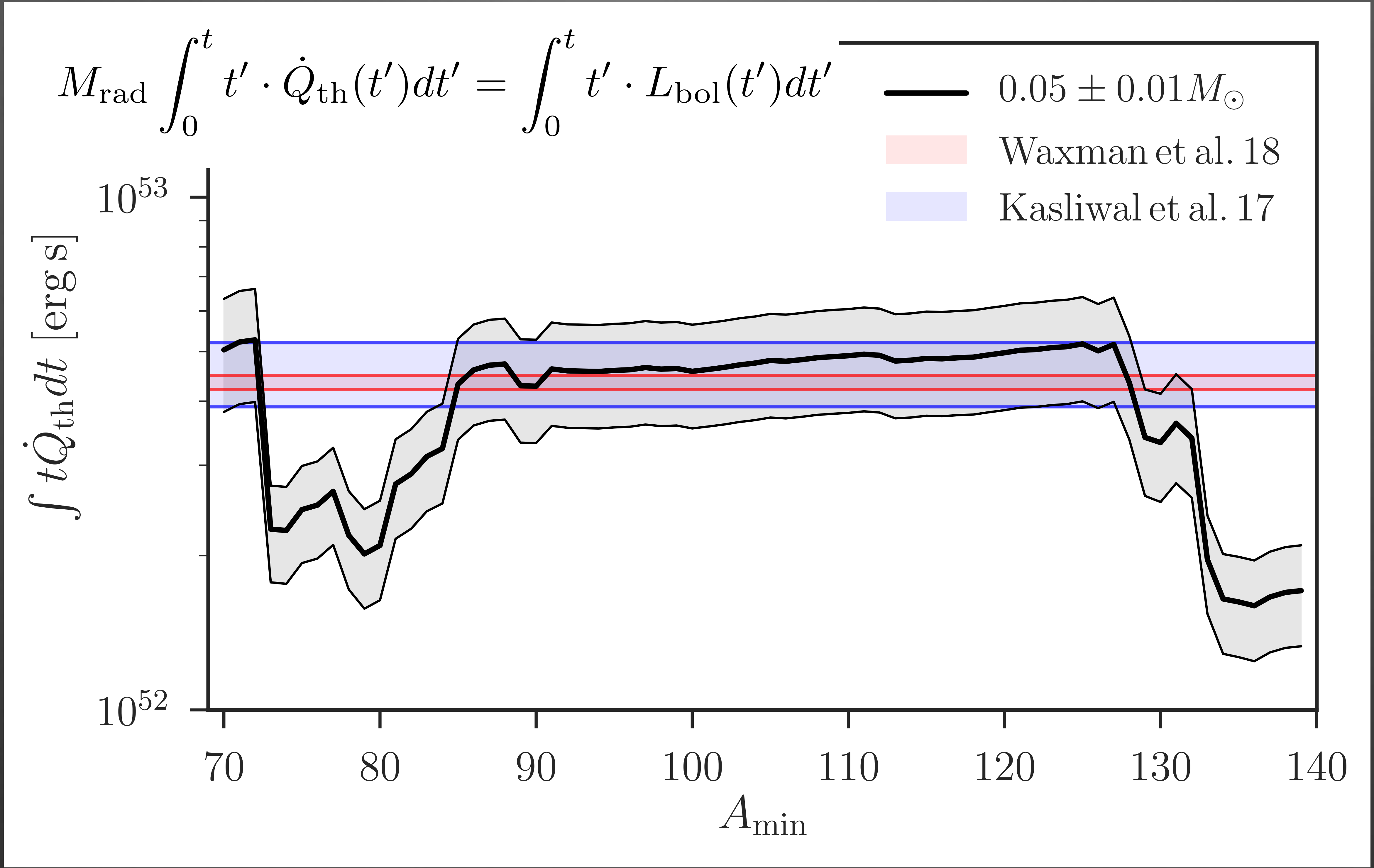


Opacity from two different codes.



- Heating rate depends on the abundance pattern.
- Different atomic codes result in different opacities.

Radioactivity and mass estimate



KH & Nakar in prep.

This estimate is insensitive to the opacity and geometry.